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:** MAY 2017 **TIME**: 3 HOURS	**EXAMINER:** PJ LE ROUX **MODERATOR:** W JOUGHIN **TOTAL MARKS:** [100] **PASS MARK:** (60%)

NUMBER OF PAGES: 11 (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

You are designing the mining of the lower portion of a pipe shaped ore body. The upper part of the ore body was extracted by open cast mining.

a) Describe in detail how the mining span required to initiate caving in a pipe shaped ore body can be assessed using rock mass rating systems. **[7]**

b) Sketch the layout of the undercut, draw-points and gathering drives. **[6]**

c) Discuss the changes in stress that will occur in the gathering drives during mining using sketches. **[6]**

d) Thence recommend suitable support for the drives and drawpoints. **[6]**

[25 MARKS]

You are designing the mining of the lower portion of a pipe shaped ore body. The upper part of the ore body was extracted by open cast mining.

a) Describe in detail how the mining span required to initiate caving in a pipe shaped ore body can be assessed using rock mass rating systems.

Laubscher's MRMR

Laubscher's stability graph – hydraulic radius

7

b) Sketch the layout of the undercut, draw-points and gathering drives.

6

c) Discuss the changes in stress that will occur in the gathering drives during mining using sketches.

Conventional or post undercut – advancing undercut induces stresses. High stress induces fractures, low stress allows unravelling

Advance undercut – limited development carried out ahead of undercut - final excavations do not see full stress change.

Post undercut – infrastructure is developed in de-stressed ground.

Stresses induced by point loading due to arching

Draw points will have long life.

6

d) Thence recommend suitable support for the drives and drawpoints.

Depends on anticipated rock mass strength and loading. Support will vary from spot bolting, to pattern bolting, pattern bolting with straps and cable bolts, yielding arches. In extreme cases planned rehabilitation and re-supporting may be required.
In severely deforming situations, long cable anchors, tensioned wire ropes, concrete archeas

QUESTION 2

A massive tabular orebody is dipping at about 30° at a depth of 70 m to 200 m below surface. The mineralized zone is on average 25 m thick and 250 m on strike. The mineralization lies on and above the contact between massive dolomite and an overlying sandstone. The sandstone extends above the mineralized zone.

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]**

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

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

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

[25 MARKS]

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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.

25m width, sandstone must be very competent to expose full width – would probably go for a layout like one below:

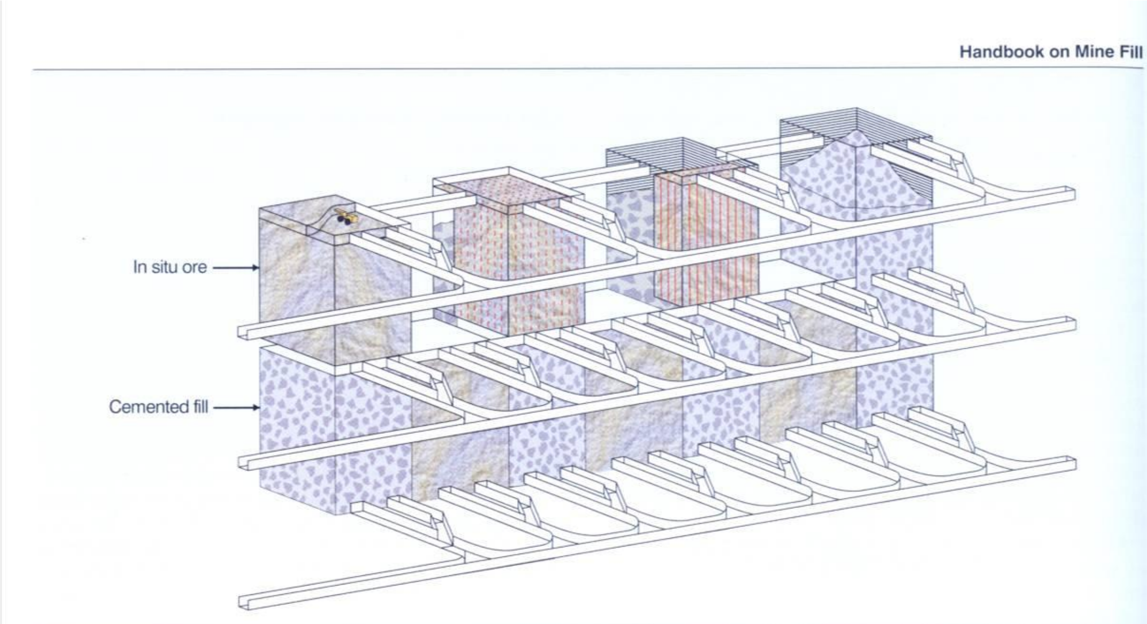


FIGURE 1.4 Schematic three dimensional view of open stope mining showing the different stages of mining, starting from left to right with pre-production, development of overcut, drilling, blasting and filling (after Potvin, 1988)

6

b) Describe the geotechnical investigations required to assess the stable spans which can be mined.

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

6

c) Describe how you would assess the stable span of the hangingwall.

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

8

d) How would you control the hangingwall span considering the mining method.

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

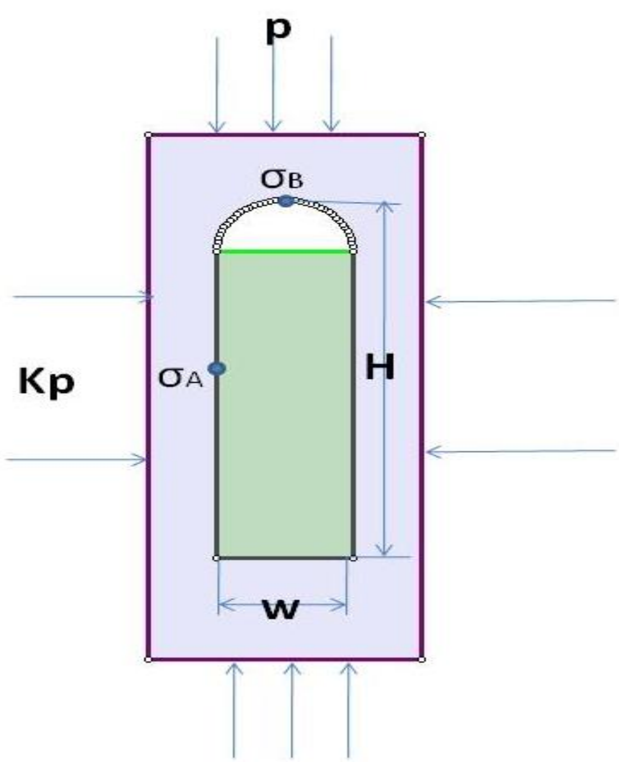
5

QUESTION 3

The figure below is a schematic representation of a section through a cut and fill stope. The stress concentration factors at the crown and sidewall can be determined using the following equations.

Crown: $\sigma B/p = K - 1 + 2K(H/W)^{1/2}$

Sidewall: $\sigma A/p = 1 - K + 2(W/H)$



a) Plot graphs of the stress concentration factor versus the H/W ratio. Use H/W values of 1,2,5,10, and 20 and K=1 **[12]**

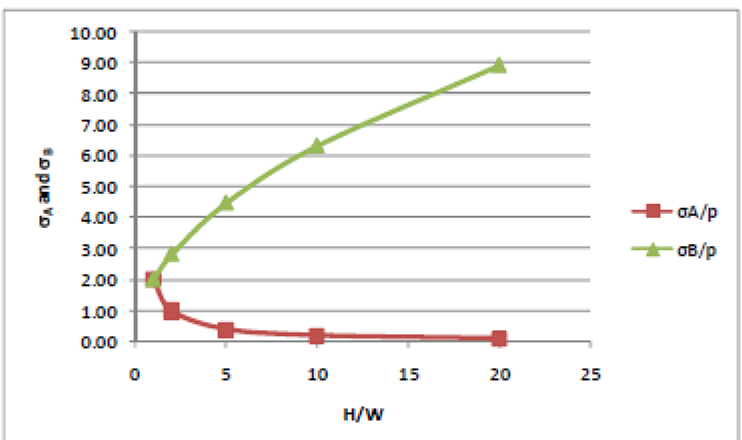
b) The stress concentrations in the crown and sidewall change as H increases. How will this influence stability? Briefly suggest methods of managing stability. **[5]**

c) Describe, with the aid of sketches, how you would carry out pre-reinforcing of the crown using long cables. **[8]**

[25 MARKS]

a) Plot graphs of the stress concentration factor versus the H/W ratio. Use H/W values of 1,2,5,10, and 20 and K=1 **[12]**

H/W	σ_A/p	σ_B/p
1	2.00	2.0
2	1.00	2.8
5	0.40	4.5
10	0.20	6.3
20	0.10	8.9



b) The stress concentrations in the crown and sidewall change as H increases. How will this influence stability? Briefly suggest methods of managing stability. **[5]**

Brady and Brown 14.4

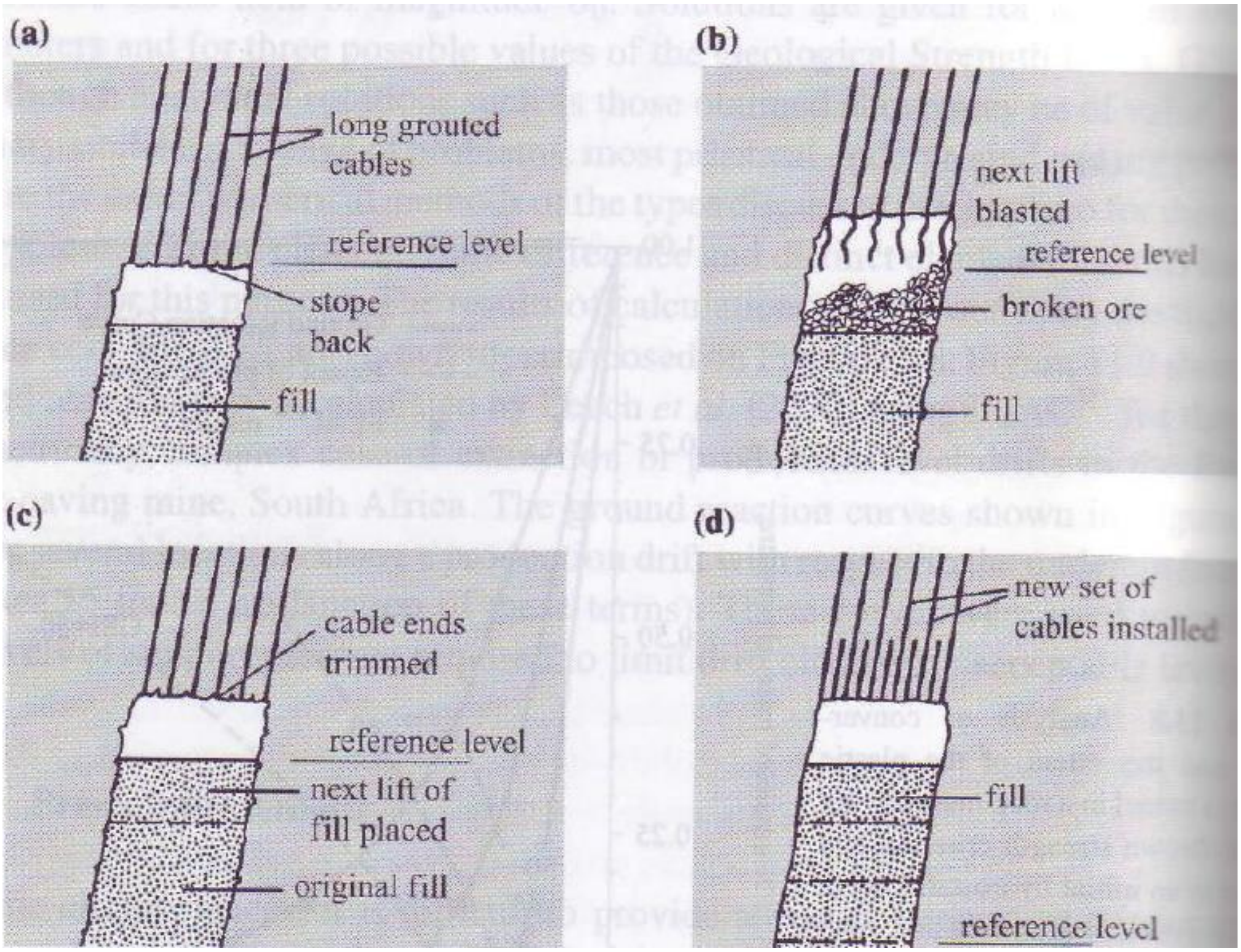
The stress in the sidewall becomes a low compressive stress (or tensile if K>1), which will allow unravelling of a blocky rock mass. The backfill prevents this from occurring. The lift heights can be reduced if the sidewall conditions are poor.

The stress in the crown increases as the H/W ration increases. If the stress levels approach or exceed the rock strength, conditions in the crown will deteriorate due to fracturing or mobilisation of blocks. This can be managed by:

- Abandoning the stope and underhand stoping from a higher level
- Development of a new overhand stop at a higher elevation and leaving a pillar.
- Pre-reinforcement of the stope crown.

c) Describe, with the aid of sketches, how you would carry out pre-reinforcing of the crown using long cables. **[8]**

Brady and Brown Chapter 11.4.
Hoek, Kaiser & Bawden 11.7.1
a) Long grouted cables are installed in the crown parallel to the stope walls (the length of several lifts).
b) The next lift is blasted,
c) Ore is removed and cable ends are trimmed
d) Successive lifts are mined until the minimum required cable support length is reached. New cables are then installed.



QUESTION 4

The following stress field data has been determined through elastic modelling in an area of a mine:

σ_{zz} = 30 kPa.m^{-1} (vertical stress gradient)

h = depth below surface

k_{xx} = 1.5 (000^0 - 180^0) (k-ratio in the x-direction - horizontal)

k_{yy} = 2.5 (90^0 - 270^0) (k-ratio in the y-direction - horizontal)

The principal stresses are aligned with the co-ordinate axes. The rock mass has a high joint density with a uniaxial compressive strength of 180 MPa. The horizontal excavations are greater than 6m x 6m.

4.1 Calculate the RCF at 500 m depth below surface for:

4.1.1. a vertical ore pass

4.1.2. a horizontal tunnel orientated East-West and

4.1.3. a horizontal tunnel orientated North-South

In each case, describe the stress distribution (elastic), expected fracturing, ground conditions and support requirements for anticipated mining-induced stress changes (no seismicity). Use annotated sketches as required. **[18]**

4.2 The depth of fracturing (R_f) around an excavation can be estimated using the following relation:

$$R_f = \left\{a * (0.5 + 1.25 * \left(\frac{3\sigma_1 - \sigma_3}{\sigma_c}\right)\right\} - a$$

Where a is the (effective) radius of the excavation.

Calculate the depth of failure for the vertical ore pass in question 2.1, which has a 5 m diameter. **[3]**

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]**

4.1 the RCF at 500 m depth below surface for:

4.1.1. a vertical shaft

4.1.2. a horizontal tunnel orientated East-West and

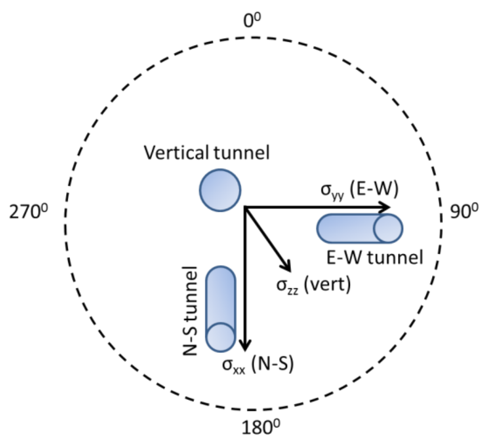
4.1.3. a horizontal tunnel orientated North-South

At 500m:

σ_{zz} = 15MPa

σ_{xx} = 22.5MPa (N-S)

σ_{yy} = 37.5MPa (E-W) ***(3)***



F = 0.5 (highly discontinuous, accept F = 0.6)

(1)

F = 90% x 0.5 (downgraded 10% for large excavations)

(1)

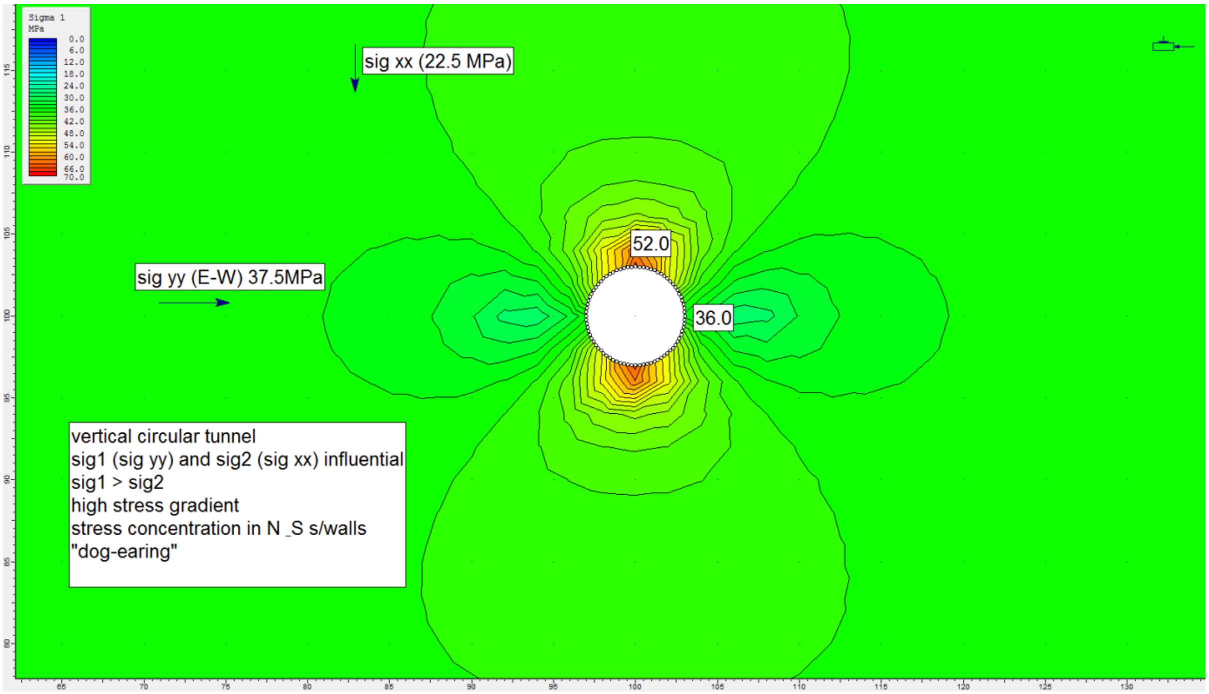
(F = 0.45 or F = 0.54)

Rock UCS = 180 MPa

In a highly discontinuous rock mass it is recommended that F is approximately 0.5, and in large excavations (> 6 m x 6 m) F may be further downgraded by 10 %. (Jager & Ryder)

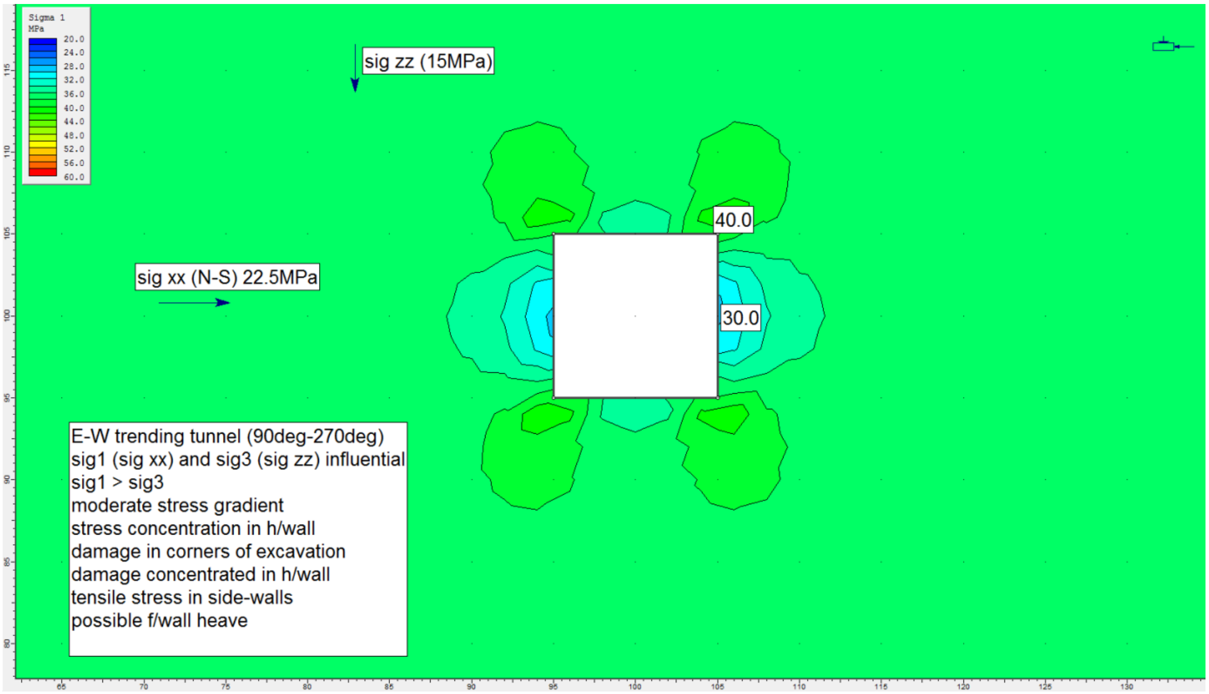
4.1.1 use σ_{xx} and σ_{yy}. σ_{zz} is parallel to tunnel axis. ***RCF = 1.0***. ***(2)*** *Circular excavation.* ***(1)*** *Primary support using fully grouted tendons or steel ropes >1.8m in length, installed as close to face as possible, on basic 2m or 1.5m pattern. Support resistance: 40-60kN/m^2. Secondary support using rope lacing an dwire mesh integrated with primary support tendons.* ***(1)*** *σ_1/UCS = 0.2. Localised brittle failure of intact rock and unravelling along discontinuities. Important to note N/S side-walls where failure is expected* ***(1)***. *Sketched and annotated stress concentrations* ***(1)***.*"Dog-ear" or spalling failure combined with block unravelling*

(5)



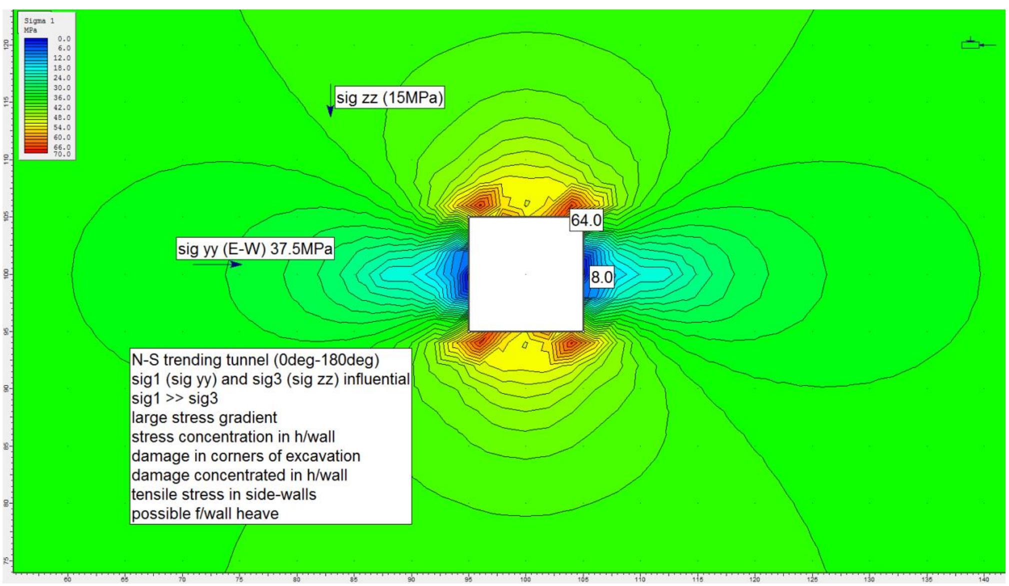
4.1.2 use σ_{xx} and σ_{zz}. ***<u>RCF = 0.65</u>****.* ***(2)*** *(Can accept support as per vertical and N-S tunnel). Regular "square/rectangular" shape. For RCF<0.7, support with "spot" bolting followed by fully grouted tendons (secondary support) > 1.5m length, installed on a basic 2m pattern. Support resistance: 30-50 kN.m^{-2}.* ***(1).*** *Moderate stress gradient. σ_1/UCS = 0.13 (where "σ_1" is σ_{xx}).* ***(1).*** *Failure modes are expected to comprise unravelling of blocks from the excavation surface.* ***(1).*** *Important to note lower stress gradient, damage concentrated in corners, migrating to the hanging-wall; no brittle failure in side-walls expected (possible tensile unravelling of blocks).* ***(1).***

(5)



4.1.3 use σ_{yy} and σ_{zz}. ***RCF = 1.2****.* ***(2).*** *Regular "square/rectangular" shape. Primary support using fully grouted tendons or steel ropes >1.8m in length, installed as close to face as possible, on basic 2m or 1.5m pattern. Support resistance: 40-60kN/m^2. Secondary support using rope lacing and wire mesh integrated with primary support tendons.* ***(1).*** *Important to note brittle failure concentrated in corners and hanging-wall.* ***(1).*** *High stress gradient* ***(1)***

(5)



(Total points = 20) **TOTAL MARKS [18]**

4.2 (2.5*(0.5+1.25*(3*37.5-22.5)/180))-2.5 = 0.31m **[3]**

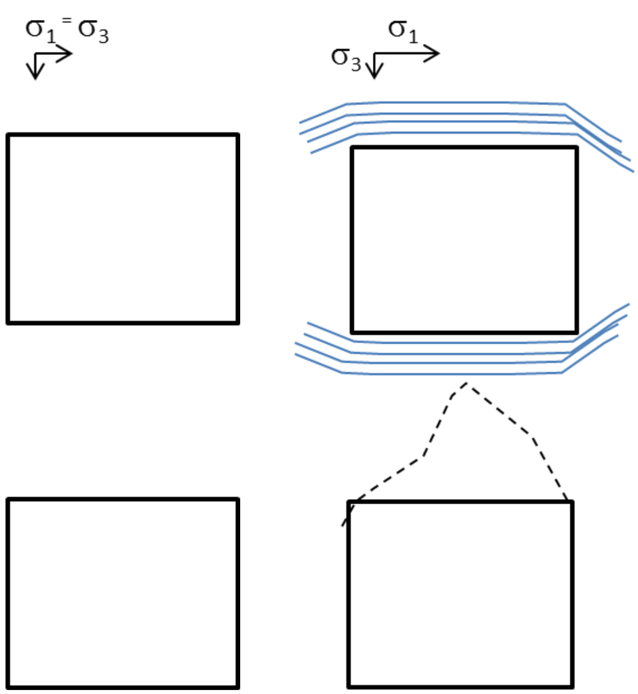
4.3 The main access ramp follows a downward spiral inclined at 9^0 to access the underground workings. Which orientations of the tunnel will experience greater stress-driven fracturing? What could you suggest to the mine manager to minimise the length of exposed tunnel to high stress concentrations?

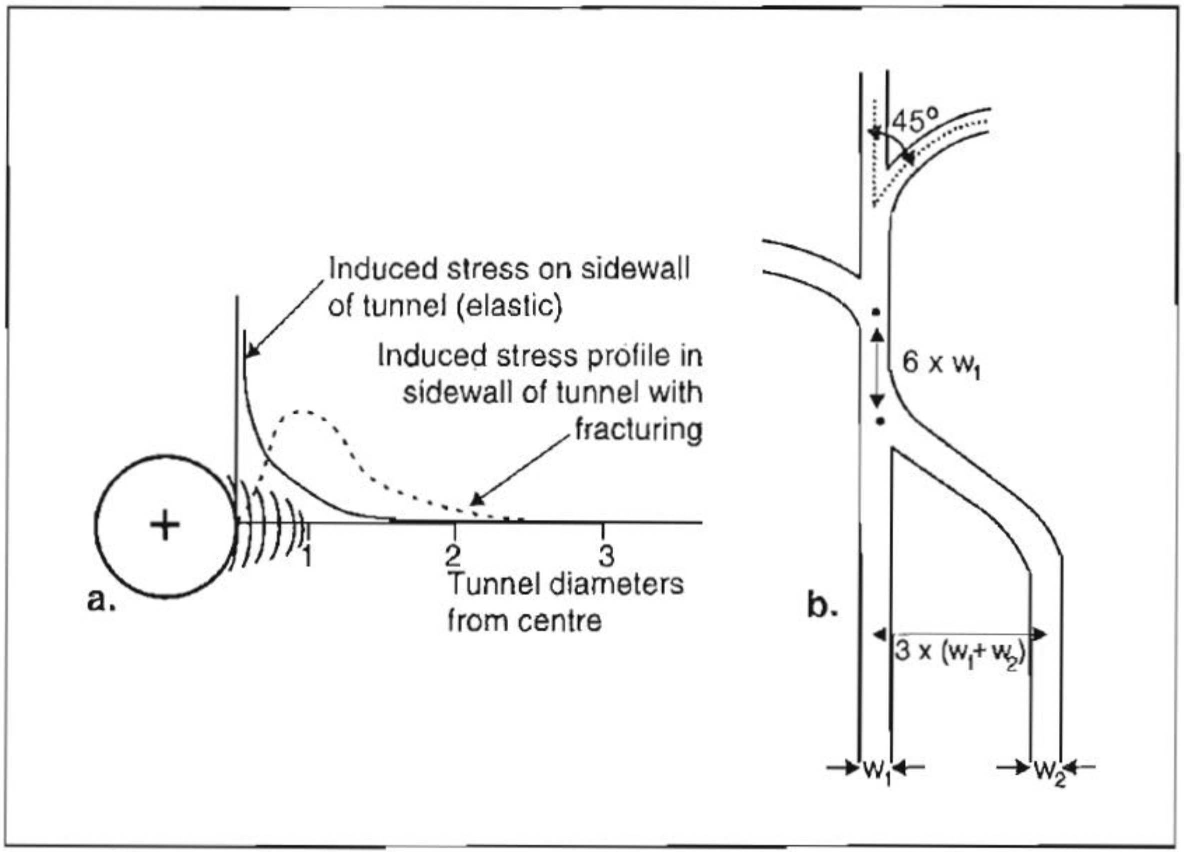
ANS: Tunnel sections orientated North-South will experience the highest stress concentrations. Increase the length of the East-West orientated tunnel segments to create a rectangular spiral connected by short N-S orientated connections. This will lower the overall support costs and increase the overall advance rates by reducing the management requirements for poor quality rock (fallout, cleanup, delays, safety). ***(4)***

Expected Stress fracturing and conditions:

Limited or no fracturing *Extensive fracturing in the roof/crown/hangingwall*

Excellent conditions *Gothic arching or buckling of roof strata*





[25 MARKS]

TOTAL MARKS: [100]