CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION FOR THE CERTIFICATE IN ROCK MECHANICS

PAPER 2

METALLIFEROUS OPTION

SUBJECT: CERT. IN ROCK MECHANICS PAPER 2 (METALLIFEROUS OPTION)	**EXAMINER:** L J GARDNER
SUBJECT CODE: COMRME	**MODERATOR:** M K C ROBERTS
EXAMINATION DATE: MAY 2007	**TOTAL MARKS:** [100] **PASS MARK:** 60%

NUMBER OF PAGES: 7

SPECIAL REQUIREMENTS:

1. **Answer *ALL THE* questions**
2. References other than those provided are not permitted. (Refer No. 10)
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.
6. Show all calculations on which your answers are based.
7. Illustrate your answers by sketches of diagrams wherever possible.
8. In answering these questions, full advantage should be taken wherever necessary of your practical experience as well as of the data given.
9. Answers must be given to an accuracy which is typical of practical conditions.
10. A list of formulae and any other essential charts and tables will be issued at time of the examination.

QUESTION 1 – GEOTECHNICAL INVESTIGATIONS

The mine on which you are employed is planning to extend its current operations, which presently stop at 1200 metres below surface, by means of a sub-level decline system. As part of this project, a large chamber must be blasted to accommodate an underground refrigeration plant. When complete, the chamber will measure 100 m long x 12 m wide x 12 m high. The area in which the chamber will be located is presently accessed by a 3 m x 3 m development crosscut. As the mine's rock engineering practitioner, you are requested to define the geotechnical environment as input into further design of the chamber.

1.1 **By means of short notes and sketches**, **describe** how you would go about this task, including:

a) Geology-related investigations (4)
b) Geotechnical investigations (7)
c) Rock property testing (4)

a – Geological investigations

(ANY 6 OF THE FOLLOWING)

- *Site mapping and / or core logging*
    - *Basic rock type (sedimentary, igneous, metamorphic)*
    - *Stratigraphy*
    - *Weathering / oxidation*
    - *Presence of ground water*
    - *Structures*
        - *Faults*
        - *Dykes*
        - *Shear zones*
        - *Unusual features / zones*
- *From data gathering, produce various models (in 2- and 3-D, with dip and strike where applicable):*
    - *Stratigraphic column*
    - *Structures*

b – Geotechnical investigations *(ANY 8 OF THE FOLLOWING)*

- *Site mapping and core scrutiny and logging*
    - *RQD*
    - *Rock mass ratings (extra ½ marks for sub-sections)*
    - *Discontinuity frequency, orientation, nature*
    - *Joint / fracture angle distribution*
- *Stratigraphy*
    - *Relative strengths*
    - *Thickness and consistency*
    - *Nature of boundaries / contacts*
- *Produce models:*
    - *Rose diagrams of joint / fracture angles*
    - *Stratigraphic isopachs*
    - *Geotechical zones / areas*
    - *Boundaries between different horizons*

c – Rock property tests

(ANY 6 OF THE FOLLOWING)

- *Field tests*
    - *Point load tests*
    - *Schmidt hammer*
- *Laboratory tests*
    - *Uniaxial Compression tests (to verify field testing)*
    - *Uniaxial or Induced Tension tests*
    - *Triaxial Compression, at 3 / 4 suitable confining pressures*
    - *Shear tests on joints / stratigraphic boundaries*
    - *If needed, swell and slake tests*
- *Use input from above to determine failure criteria*
- *From laboratory tests, also determine other mechanical properties:*
    - *Density*
    - *Young's Modulus*
    - *Poisson's Ratio*

1.2 As part of the rock property testing, you must submit samples for testing. **List** five aspects that you must pay attention to in the selection of samples (you may assume that the samples come from drilled borehole core) (5)

- *Orientation of samples in relation to layering or bedding, particularly in cases where anisotropy may play a role*
- *Core to be of suitable size (preferably approx 54 mm or more in diameter)*
- *Core sample length 2.5 – 3 x core diameter*
- *Core diameter / sample size to be greater than 10 x largest grain size*

- *Core / sample sides to be smooth and straight*
- *Samples to be free of visible discontinuities*

20 MARKS

QUESTION 2 – SUPPORT DESIGN

2.1 The Rockwall Condition Factor (RCF) is often used to determine the support requirements for an excavation. **Explain how** this factor is determined; **the implication** of different result values on the anticipated degree of failure **and** associated level of support. (5)

RCF = $(3\sigma_1 - \sigma_3) / F\sigma_c$; where 01 and 03 are the major and minor field stress components acting normal to the tunnel, 0_c is the uniaxial compressive strength of the host rock, and F is an empirical rock mass condition factor. In normal competent rock, this factor F does not deviate significantly from unity. In highly incompetent rock (in which there are both joints and weak bedding planes spaced less than about 0.1 m apart), an appropriate value of F is approximately 0.5. In large excavations (say 6 x 6 m as opposed to standard 3 x 3 m tunnels), F should be further downgraded by about 20 % to reflect the weakening effect of excavation size on effective rock mass strength.

If RCF < 0.7 conditions should be excellent, with little or no rockwall failure, requiring only primary support such as tendons. As RCF increases from 0.7 towards 1.4, ground conditions deteriorate increasingly, requiring both primary and increasing levels of secondary support e.g, meshing and lacing, with long anchors and / or shotcrete . When RCF >1.4 poor ground conditions prevail, requiring special support requirements incorporating primary, secondary and tertiary support such as steel arches.

2.2 Rockwall failure can also often be predicted from empirical criteria based on a percentage of the host rock strength. **List** several of these percentages;

describe the degree of failure that is anticipated with each point **as well as** the associated level of support. (5)

If σ_1 < 25 – 33% of the UCS (depending on rock type) conditions should be excellent, with little or no rockwall failure, requiring only primary support such as tendons. As σ_1 increases from 25 – 33 % towards 33 - 50% of UCS, ground conditions deteriorate increasingly, requiring both primary and minimal secondary support e.g, shotcreting. When σ_1 increases from 33 – 50 % towards 50 – 66 % of UCS, ground conditions are generally poor, requiring both primary and increasing levels of secondary support e.g, meshing and lacing, with long anchors and / or shotcrete. When σ_1 > 50 – 66 % of UCS extremely poor ground conditions prevail, requiring special support requirements incorporating primary, secondary and tertiary support such as steel arches.

2.3 The host rock in the vicinity of the refrigeration plant chamber proposed in question 1 has a UCS of approximately 150 MPa. The Rock Mass Rating in the area is approximately 55, using the GSI system. Based on the depth of 1200 metres below surface, a mean rock density of 3 tons / cubic metre and assuming a k-ratio of 1.2, **describe** the level of rockwall failure that you anticipate using:

a) The RCF criteria (2)

$RCF = (3\sigma_1 – \sigma_3) / F\sigma_c$

Σ_{vv} at this depth = 35.3 MPa, while σhv = 42.4 MPa. Given the RMR of 55, a suitable value for F = 0.5, particularly if considering that this is a large chamber, therefore:

RCF = (3 x 42.4 – 35.3) / (0.5 x 150)

RCF = 1.225

This implies that both primary and substantial secondary support would be required.

b) The empirical criteria (2)

σ_1 = 28.3 % of the UCS, and therefore using the lower limits of the empirical criteria falls into the section requiring primary support with minimal secondary support.

2.4 In light of the above work, **compile** an appropriate support system for the proposed refrigeration plant chamber, **specifying** in each case the type of support unit / structure, the relevant length / thickness and applicable spacing for the:

a) Primary support (4)

b) Secondary support (4)

c) Tertiary support (3)

You may assume that the chamber will be developed under virgin conditions and will be situated in a statically-loaded environment.

Given the large dimensions of the chamber as well as its long-term nature, it is prudent to adopt a cautious design. This could for example comprise:

a) Primary support – resin-grouted bolts or post-grouted mechanical anchors, 2.2 m long x 16 or preferably 20 mm diameter (corrosion potential in refrigeration chamber), installed at a minimum of 70º to the rockwall, on a 1.0 m x 1.0 m spacing.

b) Secondary support – areal coverage in the form of meshing and lacing, typically on a 2.0 m diamond pattern and covered by a 50 mm thick sealing layer of shotcrete, or else a 75 mm thick layer of (preferably polypropylene or else stainless steel fibre) fibre-reinforced shotcrete.

c) Tertiary support – post-grouted prestressed cable anchors, 4.5 m and 6.5 m long x 37 ton capacity, installed in the hanging wall in a ring pattern with longer anchors in the centre, spaced on a 2.0 m x 2.0 m pattern.

25 MARKS

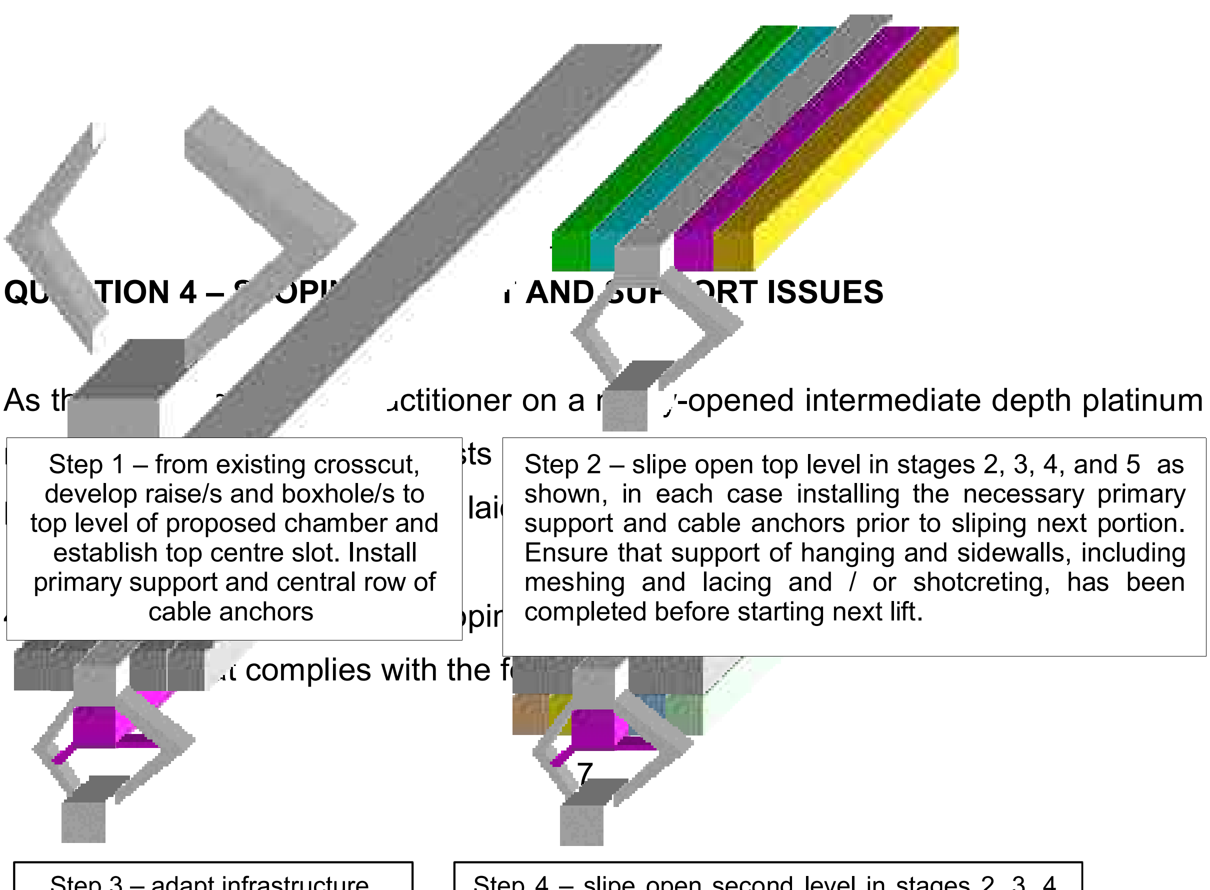
QUESTION 3 – MINING LAYOUTS

Your mine's project team is informed that approval has been granted to mine the refrigeration chamber proposed in question 1. You are now required to design an appropriate extraction and support sequence. The completed chamber will measure 100 m long x 15 m wide x 12 m high. Access to the area is provided by a 3 m x 3 m development crosscut, which intersects the bottom corner of the proposed chamber.

3.1 **Describe and explain using sketches** how you would extract and support the chamber, using a multi-stage approach. Make use of information and answers from questions 1 and 2 as far as possible. You must **show** for each stage:

a) The extent of mining for that stage

b) The support required to be installed prior to moving on to the next stage, whether primary, secondary or tertiary. (15)



QU TION 4 – OPI ' AND SU RT ISSUES

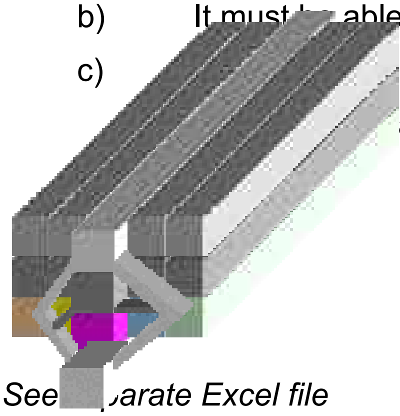
As th ...ctitioner on a ...-opened intermediate depth platinum ...ts ... lai ... pi ... complies with the f next centre slot.

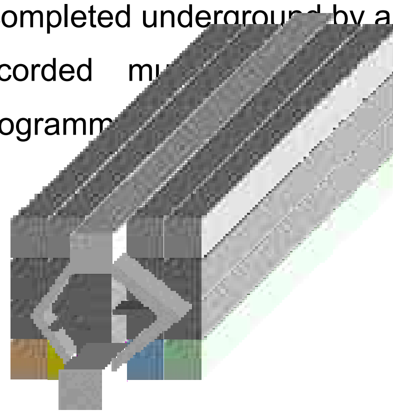
including meshing and lacing and / or shotcreting, has been completed before starting next lift.

a) It must fit onto a maximum A3-size sheet

b) It must be able to be completed underground by a semi-skilled person

c) ... ion recorded m... transferable to a ... ased programm... further processing





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Steps 5 and 6 – open next level, slip and support as previously prior to moving on.

QUESTION 5 – BACKFILL COMPARISON

Backfill is often proposed as an effective support medium, with various types of backfill available to suit a wide variety of applications.

5.2 **By means of a table, list and compare** four different types of backfill, their **relative** advantages, disadvantages and typical applications. (20)

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.*

Additional information is given on some of the systems below, and the advantages and disadvantages of the systems are then summarized briefly in Table 1. It should be noted that imported fill can also be used when such material is economically available, an example of such a case being Black Mountain Mine. This is rather uncommon, however.

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 40-150μm range of particle size and the proportion of -10μm material is less than 4%. The -10μm 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. Backfill additives have been developed that:

- *reduce water run-off to a minimum (to less than 5%);*
- *achieve high early strength with minimal shrinkage;*
- *contain a relatively low total additive addition (typically less than 6% by dry mass);*
- *have a relatively high angle of repose (slightly less than achieved by paste filling);*
- *can be transported over kilometres using gravity alone.*

Binder in the form of a cement/pozzalan blend and a silicate activator is added to the full plant tailings (can be used with deslimed tailings as well). The activator gels the water in a stable form and hydration takes place. Slurry fill systems can thus be designed to match a specific paste system and tend to be far simpler to operate. In South Africa, where the required binders are readily available, this system is less costly than paste fill systems.

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.

Table 1 Advantages and disadvantages of fill systems

System	***Advantages***	***Disadvantages***	***Remarks***
Crushed Waste Fill	*- Available waste rock on surface can be used if tipping through a pass system is appropriate - Hoisting time on shaft is reduced if waste is crushed underground - Immediate access is possible on the fill by heavy equipment*	*High cost of crushing underground High cost of transport Confinement provided to pillars not as good as with some other types of backfill*	*Sufficient waste must be available or generated*
Classified cycloned tailings (CCT)	*- Simple method of conveying large volumes of fill from surface directly into areas to be filled - Has good drainage characteristics*	*Large volumes of excess water have to be handled underground Use of only the coarser fraction, leaving the finer fraction for tailings disposal creates potential problems with the building of slimes dams More difficult to pump than full plant tailings*	*Sufficient backfill material must be available*
Cemented Full Plant Tailings	*- Simple method of conveying large volumes of fill from surface directly into areas to be filled - Maximum use of tailings product - Very good pumping characteristics*	*Poor drainage characteristics High moisture content requires greater quantities of binder*	*The binder material assists by hydrating the excess water retained by the fines*
Paste Fill	*- Relatively small amounts of cement (3% to 5%) produce stiff backfill (1.5 to 3.5MPa) - Reduced tailings impoundment requirements - Good support properties - Reduced spills underground - The entire tailings stream can be placed underground*	*Costly system which requires expensive pumps, pipes and dewatering equipment Conveying distances limited due to high pressure gradients (approximately 1km horizontally) Good quality control is necessary*	*Pumping difficulties can be alleviated by pumping the fill underground as a slurry and then dewatering it close to the stopes*
Slurry Fill	*- Very little run-off water - Can be used with full plant tailings - The total cost of this system could be less than for cemented CCT*	*Requires availability of a special binder Accelerator is costly and requires accurate dosing*	*Technically, this system is good*

20 MARKS