CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION PAPER MEMORANDUM

SUBJECT: CERTIFICATE IN ROCK MECHANICS PAPER 3.1 : HARD ROCK TABULAR **SUBJECT CODE:** COMRMC **EXAMINATION DATE:** MAY 2015 **TIME**:	**EXAMINER:** PJ LE ROUX **MODERATOR:** WM BESTER **TOTAL MARKS:** [100] **PASS MARK:** (60%)

NUMBER OF PAGES: 13

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

SPECIAL REQUIREMENTS:

1. Answer **ALL FIVE** of the five 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 – MULTIPLE CHOICE

Only write the question number and the answer. **Example**: 1.1 (a)

1.1 Extension fractures

a) A fracture that develops parallel to the direction of greatest stress and parallel to the direction of compression

b) A fracture that develops perpendicular to the direction of greatest stress and parallel to the direction of compression

c) A fracture that develops perpendicular and parallel to the direction of greatest stress and perpendicular to the direction of compression

d) A fracture that run perpendicular to the direction of smallest stress and parallel to the direction of compression

(2)

1.2 The presence of 'rock flour' (white powder) on structures (fractures, joints, faults, etc) indicates

a) the occurrence of substantial strain on the structures

b) the occurrence of substantial stress on the structures

c) the occurrence of substantial closure on the structures

d) the occurrence of substantial displacements on the structures

(2)

1.3 Rockfall height can be defined as

a) the rockburst height of rock that dislodged and collapsed into the mining excavation

b) the rock that dislodged and collapsed into the mining excavation

c) the thickness of the rock that dislodged and collapsed into the mining excavation

d) the length of the rock that dislodged and collapsed into the mining excavation

(2)

1.4 In quasi-static conditions, shallower mines generally have

a) a higher fall out height compared to deeper mines

b) a lower fall out height compared to deeper mines

c) no difference in fall out height compared to deeper mines

d) none of the above

(2)

1.5 The thickness of strata to be supported is 1.6m. The density of the rock is assumed to be 2750 kg/m^3 and the gravitational acceleration is taken as 9.81 m/s^2. The support resistance criterion required to support the above mentioned would be:

a) 16,8 kN/m^2

b) 38,6 kN/m^2

c) 43,2 kN/m^2

d) 42,3 kN/m^2

(2)

1.6 Commonly factors of safety of between

a) 1.2 and 1.5 are applied to support design

b) 0.9 and 1.6 are applied to support design

c) 1.6 and 2.0 are applied to support design

d) >2.0 are applied to support design

(2)

1.7 The word abutment when used on the mining operations simply means:

a) the 'corner' of the unmined rock around a mined out area

b) the 'edge' of the unmined rock around a mined out area

c) the 'start end' of the unmined rock around a mined out area

d) the 'end' of the unmined rock around a mined out area

(2)

1.8 A '45° rule' is normally referred to,

a) to ensure that the tunnel will not be placed in the low stressed abutment stress lobes

b) to ensure that the tunnel will be placed in the highly fractured abutment stress lobes

c) to ensure that the tunnel will be placed in the highly stressed abutment stress lobes

d) to ensure that the tunnel will not be placed in the highly stressed abutment stress lobes

(2)

1.9 In very shallow stopes (depths < ± 400mbs), in-stope pillars are required to carry the

a) full weight of overburden up to surface due to the absence of stress levels sufficient of assisting stability
b) full length of overburden up to surface due to the stress levels sufficient of assisting stability
c) full weight of overburden up to surface due to the presence of high stress levels sufficient of assisting stability
d) full weight of overburden up to 20m from surface due to the absence of stress levels sufficient of assisting stability

(2)

1.10 In shallow mining depth stopes approximately 40mbs, the use of
a) crush in-stope pillars is required
b) non-yield in-stope pillars is required
c) yielding in-stope pillars is required
d) none of the above

(2)

[20]

QUESTION 2

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.

2.1 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

2.2 How would one apply Bieniawski's RMR_{76} and RMR_{89} rating values to obtain GSI values (3)

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

2.3 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:

2.3.1 Strain softening (3)

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

2.3.2 Stress tensor (3)

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

2.3.3 Off reef field points (2)

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

[20]

QUESTION 3

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

3.1.1 Calculate the yield load of the roof bolt? (2)

3.1.2 Determine the minimum support density required to support the shale layer? (2)

3.1.3 What will the maximum bolt spacing be for a factor of safety of 1.0? (2)

3.1.4 Given that the resin-steel bond strength is 5MPa and the resin-rock bond strength is 2000kPa. Determine the critical bond length. (2)

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 m^2 = 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

3.2 Discuss how geological structures can impact on rock mass behaviour and tunnel stability in the following manners:

3.2.1 Bedding planes (3)

3.2.2 Joints (3)

3.2.3 Faults (3)

3.2.4 Dykes (3)

[20]

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")

QUESTION 4

4.1 Discuss the siting of tunnels with respect to existing, current and future stoping operations? (6)

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.*

4.2 Discuss the effect of stress fracturing and geological structure on the final shape of vertical and inclined shafts? (3)

Stress fracturing and geological structures will, if left uncontrolled, create dog-eared excavation shape in shafts and orepasses. Weak zones will 'self-mine' along the weak zone. The large difference is normally that shafts are well supported during sinking with tendons, mesh, shotcrete and the concrete lining, all of which inhibits the scaling of the shaft walls. However, the intersection of very poor rock types will create a similar shape to that shown for orepasses intersecting weak material types

4.3 Discuss the conditions that may lead to the formation of instabilities in rock passes (6)

- *Stress*
- *Geology*
- *When rock passes exceed lengths of 70m, impact abrasion due to falling rocks and friction abrasion due to large weight of the material flowing through the rock pass become severe and may result in the fracturing and hence fall-out of rock fragments from the sidewall. Also consider inclination, number of legs and angle of corners (breakaways), if developed by hand.*

- *Another factor that is commonly forgotten is the placement of rock passes in relation to other infrastructure (excavations). Stress interaction between the orepass and other excavations increase potential for stress fracturing and scaling.*
- *Water flowing through then rock pass reduces the strength of geological discontinuities exposed in the rock pass walls. This reduction in strength can easily result in scaling when displacement is induced on the discontinuities by falling and sliding rock material.*
- *It is good practice to keep a rock pass as full as possible, as that reduces the impact abrasion and therefore also the potential for scaling. By emptying a rock pass, conditions are created where the next material tipped into the rock pass fall through large distances and exert large forces on the walls at the point of impact.*
- *Blasting within rock passes when material 'hangs up' is not a great practice to ensure stable rock pass walls. The blasting causes significant air pressure (shock wave) and vibration within the rock pass, both of which increase potential for scaling. At the same time, the material loosened by the blast falls collapses down the rock pass and impacts on the rock pass walls, increasing potential for scaling.*

4.4 When mining takes place close to surface, subsidence of the surface can cause severe damage to surface structures such as buildings, roads and railway lines. Van der Merwe (1991) classified surface subsidence into classes of severity using the ratio between the mining height (Sm) and depth (H) as range indicator. Complete the description of the Table below:

Class	Sm/H ratio	Description
A	<0.001	4.4.1
B	0.001-0.005	4.4.2
C	0.005-0.02	4.4.3
D	0.02-0.05	4.4.4

E	>0.05	4.4.5

(5)

[20]

4.4.1 Barely noticeable, smooth, continuous profile, hair-line cracks

4.4.2 Difficult to notice, smooth profile, cracks 1-2 cm wide

4.4.3 Noticeable in flat terrain, smooth, cracks 2 – 10 cm wide, compression ridges 1 to 5 cm high

4.4.4 Noticeable in most terrains, visible vertical displacements across cracks, cracks 10 to 50 cm wide, compression ridges 5 to 50 cm high

4.4.5 Severe profile, almost vertical sides, cracks wider than 50 cm, compression ridges higher than 50 cm

QUESTION 5

5.1 The Table below lists typical characteristics for a number of support units. It is critical that each support unit utilised within a support system should be classified in terms of these characteristics to ensure that the support is appropriate to the conditions. Please complete the Table. Indicate if the support element Initial stiffness, yield capacity and shear capacity is poor, fair, good or very good. For the load capacity indicate if it is low, medium or high.

(20)

<table>
<tr><th colspan="2">Support element</th><th>Initial stiffness</th><th>Yield capacity</th><th>Load capacity</th><th>Shear capacity</th><th>Comments (applicability)</th></tr>
<tr><td>Friction tendons:</td><td>Swellex / splitset</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">End anchored Pre-tensioned:</td><td>Rockstud</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Cable anchor</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Fully grouted:	Smooth bar					
	Rebar					
	Drill steel					
	Yielding tendon					
	Cable tendon>4m					
	Wire loops,3m					
Sets:	Arches and Cribbing					

[20]

TOTAL MARKS: [100]

Support element		Initial stiffness	Yield capacity	Load capacity	Shear capacity	Comments (applicability)
Friction tendon:	Swellex/ split set	Fair	Fair	Low	Fair/poor	Simple installation, corrosion a problem, primary support only
End anchored Pre-ten-sioned:	Rock stud	Very good	Poor	Medium	Fair	Used under low stress conditions.
	Cable anchor	Very good	Fair	High	Good	Large excava-tions/wide areas
Fully grouted:	Smooth bar	Good	Fair	Medium	Fair	Easily debonded, re-quires good grouting
	Rebar	Very good	Poor	Medium	Poor	High initial stiffness, requires good grouting
	Drill steel	Very good	Poor	High	Poor	High shear resistance
	Yielding tendon	Fair	Very good	Medium	Fair/good	Good yieldability
	Cable tendon>4m	Fair	Fair/ poor	High	Good	Yieldability + flex-ibility, may require good grouting
	Wire loops,3m	Fair	Fair/ poor	Medium	Good	Yieldability + flex-ibility, may require good grouting
Sets:	Arches and Cribbing	Poor	Fair	High		Areal coverage in poor areas