**National Exams December 2012**

**09-Mmp-A2, Underground Mining Methods and Design**

**3 hours duration**

**NOTES:**

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. One only reference sheet, 8.5 x 11 inch, hand written both sides is allowed in the exam. This is a Closed Book exam, therefore only the approved Sharp or Casio type calculators are permitted.

3. Compulsory Question 1 and FOUR (4) other questions constitute a complete exam paper.

   Only question 1 and the first four optional questions as they appear in the answer book will be marked. You must select four questions from the "optional" Questions 2 to 7. Be sure you understand that two of Questions 2 to 7 must not be answered.

4. Compulsory Question 1 is worth 40 marks. Each optional question is of equal value (15 marks). Four optional questions plus Question 1 constitute a complete exam paper.

5. Many questions require an answer in essay format. Clarity and organization of the answer are important. Use sketches and drawings to illustrate your answers whenever possible.

## Question 1 (40 marks)

*You must answer all of this question, parts 1.1 to 1.7 inclusive*

### Question 1.1 (6 marks)

*answer compulsory*

1.1 Describe and compare, with examples of usage, the following support systems;

1.1.1 Common anchor threaded roof bolt.
1.1.2 Split set bolt.
1.1.3 Cable bolt.

(2 marks each)

### Question 1.2 (5 marks)

*answer compulsory*

1.2 Discuss the geology, geometry and rock strength issues applicable to room and pillar mining.

5 marks

### Question 1.3 (5 marks)

*answer compulsory*

1.3 Discuss the geology, geometry and rock strength issues applicable to the vertical crater retreat mining method.

5 marks

### Question 1.4 (6 marks)

*answer compulsory*

1.4 A general mine hoist question.

1.4.1 When choosing a type of hoisting rope, what are the two most important rope properties.

1.4.2 What is the most important factor in selecting the size of a hoisting rope.

1.4.3 Why is the ratio “hoist drum diameter to rope diameter” important, and what are typical values.

1.4.4 In shaft hoisting what do you understand by the term ‘overwind’.

1.4.5 Three methods can be used to prevent overwind. What are they and briefly describe how they achieve their objective.

(1 mark each except 1.4.5 which carries 2 marks)

**Question 1.5 (6 marks)** ***answer compulsory***

1.5 A general mine ventilation question.

Describe methods for measuring air velocity in underground mines when the air velocity is;

1.5.1 Slow moving; e.g. a depleted and closed off area of the mine.
1.5.2 Moderate velocity; e.g. supplying air to a working stope.
1.5.3 High velocity; e.g. at a large (say 2m diam.) fan underground with closed ventilation doors.

In hot, deep, underground mines;

1.5.4.1 How is the water content of mine air measured, and why is the water content so important.
1.5.4.2 In order to improve employee productivity, what infrastructure might typically used.

(1 mark each except 1.5.4.1.which carries 2 marks)

**Question 1.6 (6 marks)** ***answer compulsory***

1.6 A general question on the haulage of rock to surface in underground mines.

There are many practical methods of moving rock (ore and waste) from underground workings.

With the aid of neat sketches, very briefly describe the many methods (at least 4) which you might consider, including typical "tonnes per day" capacity ranges.

(1.5 marks each)

**Question 1.7 (6 marks)** ***answer compulsory***

1.7 Costs

In the context of underground mine cost estimating, what do you understand by the following terms, and describe the function and development of these terms.

1.7.1 The Marshall and Swift Mine/Mill cost index (M&S M/M)

1.7.2 The "six tenths rule" (the rule may also be referenced as the 'two thirds' or 0.7 rule depending on the practitioner)

1.7.3 List the cost centers on which the Marshall and Swift (and many other) indices for mining are based.

(2 marks each)

**Question 2 (15 marks)** **One of Four Optional Questions**

2.0 Draw neat sketch diagrams and use these to describe the development and production cycle of operations of "conventional" room and pillar mining in hard rock.

The answer should include sketches and/or descriptions for the following;

2.0.1 Initial cross-cuts and drifts from the shaft

2.0.2 Initial stope access.

2.0.3 Starter stope

2.0.4 Stope at the peak of production

2.0.5 Support for stability and how this might be designed, including ore losses both permanent and temporary.

2.0.6 The sequence of mining a set of stopes.

2.0.7 Pillar reclamation and mining.

2.0.8 'Permanent' stabilization of the mined out area

1 mark each

2.1 Where the "ore" is soft, continuous mining machinery can be applied. Compare and contrast "conventional" hard rock and "continuous" soft ore room and pillar operations with respect to "services", ventilation and roof support.

2.2 In the mining of thick seams (greater than 6 m high), a technique sometimes referred to as "stope-and-pillar" mining can be used. Describe how this method differs from the methods in 2.0 and 2.1 above.

2.3 In the late 1960's, Gaspe Copper re-designed their on-going room and pillar operations to utilize horizontal and vertical drill jumbo's, small cable shovels (2-3 $m^3$ bucket) and 30 tonne trucks in their underground operations. What advantages did the choice of such equipment provide to Gaspe, and what disadvantages.

2 marks each except 2.2 which carries 3 marks

**Question 3 (15 marks)** **One of Four Optional Questions**

3.0 Draw a neat sketch diagram and use it to describe the development and production cycle of operations utilizing the vertical crater retreat (VCR) method of mining. Clearly show examples of the following in your sketch,

"raise", "slot" and "stope" in 3.0.2 and 3.0.3 below 2 marks

***Question 3 continued***

The answer should include sketches and/or descriptions for the following;

3.0.1 Initial cross-cuts and drifts from the shaft

3.0.2 Initial stope access.

3.0.3 Starter stope

3.0.4 Stope at the peak of production

3.0.5 Support for stability and how this might be designed, including ore losses both permanent and temporary.

3.0.6 The sequence of mining a set of stopes.

3.0.7 Pillar reclamation and mining.

3.0.8 'Permanent' stabilization of the mined out area

1 mark each

3.1 With the aid of a further sketch, show how low cement ratio tailings fill can be used to improve ore recovery and reduce dilution in VCR mining

3.2 In VCR, the term "crater" is used with reference to the work of C.W. Livingston. Describe how the drilling, explosive loading and blasting cycle in practical VCR mining is amended to approximate the "spherical charge" typical of crater blasting. Discuss the types of drill used, how explosives are loaded, how the blast pattern is initiated, and how the blast pattern is delayed to avoid "frozen" rock.

3.3 Describe at least three ore loading methods/machines used in VCR and discuss how appropriate ventilation can be provided to these methods/machines. What advantages do the ore loading methods/machines provide, and what disadvantages.

2 marks each except 3.1 which carries 1 mark.

**Question 4 (15 marks) One of Four Optional Questions**

Using a simple friction hoist with the hoist sheave at the top of a tall vertical building of reinforced concrete centered over the shaft as an example;

4.1 What do you understand by the term "hoist duty cycle" and what hoist selection parameters are defined by such a duty cycle. An orderly flow and very brief explanation of the parameters is expected as an answer.

4.2 What do you understand by the term "hoist motor power requirements" and how are the differing power requirements for DC and AC systems obtained. Again, an orderly flow and very brief explanation of the parameters is expected as an answer.

***Question 4 continued***

A simple head-frame mounted, balanced friction-sheave hoist has the following operating conditions.

| | | |
|---|---|---|
| Shift time | 7.2 hours | |
| Shifts/day | 3 | |
| Skip capacity | 11 tonnes | (12.12 short tons) |
| Cycle time (1 trip) | 85 sec/skip | |

4.3 What is the daily production

4.4 What is the approximate energy consumption per skip hoisted given;

| | | |
|---|---|---|
| average power consumed | 730 kW | (975 hp) |
| hoist efficiency | 85% | |
| acceleration time | 6.5 sec | |
| constant velocity time | 63.5 sec. | |

4 marks each excepting 4.3 which carries 3 marks

**Question 5 (15 marks)** **One of Four Optional Questions**

In describing mine ventilation systems, what are Kirchhof's first and second laws, and what is Atkinson's equation. How are these used in the design of mine ventilation systems.

4 marks

Four airways have been designed in parallel with a total of 47.19 $m^3/s$ (100,000 cfm) of air flowing through them.

The resistances of the airways are as follows;

| Airway Number | Resistance R $N.s^2/m^8$ | (imperial R x $10^{10}$) ($in.min^2/ft^6$) |
|---|---|---|
| 1 | 2.627 | (23.50) |
| 2 | 0.151 | (1.35) |
| 3 | 0.349 | (3.12) |
| 4 | 0.397 | (3.55) |

Calculate

| | |
|---|---|
| 5.1 | Equivalent resistance $R_{eq}$ |
| 5.2 | Head loss of the parallel airways Hl |
| 5.3 | Quantity of air flowing in each airway $Q_1$ to $Q_4$. |
| 5.4 | The sum of airflows Q (the sum $Q_1$ to $Q_4$) |

3 marks each except 5.4 which carries 2 marks

**Question 6 (15 marks)** **One of Four Optional Questions**

A mining company is reviewing two commonly used methods of moving rock from an underground mineral deposit, and has limited its choices to two alternatives, "skip and vertical shaft", and "truck and decline".

6.1 Describe the fundamentals of each system, including a neat sketch for each case.

3 marks

In making their choice, the company requires two sets of costs in each case, i.e. capital and operating. The deposit geometry and associated material (depth, size of ore-body, rock strength) are also considerations.

6.2 Prepare a "spread sheet" type design report for the company which details the component inputs to (6.2.1) capital and (6.2.2) operating costs for skip/shaft and truck/decline operations. The "spread sheet" must discuss variable deposit size/geometry, rock strength and production capacity such that the company can make informed and accurate decisions regarding typical deposits in its business portfolio.

Quote actual costs where you are able.

9 marks

6.3 Draw conclusions as to which conditions favour one material handling method or the other (skip/shaft or truck/decline). Under what circumstances could each method be used effectively to advantage over the other.

3 marks

**Question 7 (15 marks)** **One of Four Optional Questions**

7.1 You have been asked by your employer to provide some quick fixed capital cost estimates for the underground section of a mine. Who would you communicate with to provide a quick estimate +/- 40% within a day. 0.5 marks

7.2 What do you understand by the "O'Hara Capital Cost Estimation Method" as published in the Canadian Institute of Mining Bulletin, February,1980 and further described by Mular and Poulin in "CapCost, CIM Special Volume 47, 1998" and elsewhere in SME and other publications. 2 marks

7.3 Working today as a capital cost estimator, how would you convert 1980 and 1998 costs to present day (2012) and say 2015 estimates. 0.5 marks

7.4 The following are formulae for estimating the fixed capital costs of an underground mine.

If you make an obvious, substantial and extremely large error in an estimated value, use a more logical answer in subsequent calculations and ***be sure to indicate this in your exam answer***.

**Question 7 continued**

The mine has a circular shaft, 600 m deep in relatively weak rock. The mining method utilizes 10 m wide stopes, and the shaft must hoist 4500 metric tons/day ore plus 1000 mt/day waste. The mine development reserve is 2000 x T = 2000 x 4500 = 9,000,000 mt (about 5 ½ years).

7.4.1 Equation $D_S$ for cemented circular shafts in weak rock, $D_S = 1.608\ T^{0.15}$ where $D_S$ is the shaft diameter (m) and T the daily tonnage in metric tons (mt/day or tonnes/day) hoisted.

*As an example, the shaft diameter Ds is calculated for you as follows;*

$D_S = 1.608 \times T^{0.15} = 1{,}608 \times (4500 + 1000)^{0.15} = 1.608 \times 5500^{0.15} = 1.608 \times 3.64 = 5.85$ m

7.4.2 The shaft sinking cost for a circular concreted shaft (Equation $C_{12}$) is given by

$C_{12} = 314838.7 \times D_S^{0.5} + 3738.1 \times F \times D_S^{0.7}$ where $D_S$ is shaft diameter (5.85 m) and F shaft depth (600 m).

Calculate cost $C_{12}$. 0.5 marks

7.4.3 The hoist drum diameter (d) in meters is given by the following equation where (h) is hoisting distance (assume to be shaft depth, 600m ) and T the tonnes hoisted per day,i.e. 5500 mt/day.

$d = 0.0254 \times (44.09 \times T + 191.97 \times h^{0.5} \times T^{0.6} + 1.6051 \times h^{0.3} \times T^{1.2})^{0.357}$.

*As an example, the hoist drum diameter (d) is calculated for you as follows;*

$d = 0.0254 \times (44.09 \times 5500 + 191.97 \times 600^{0.5} \times 5500^{0.6} + 1.6051 \times 600^{0.3} \times 5500^{1.2})^{0.357}$

$d = 0.0254 \times (242{,}495.0 + 191.97 \times 24.495 \times 175.476 + 1.6051 \times 6.815 \times 30791.8)^{0.357}$

$d = 0.0254 \times (242{,}495.0 + 825{,}141.7 + 336{,}824.0)^{0.357} = 0.0254 \times (1{,}404{,}460.7)^{0.357}$

$d = 0.0254 \times 156.55 = 3.976$ m

7.4.4 The head-frame height in meters is given by $L = 3.0 \times d + 0.1023 \times d^3 + 1.983 \times T^{0.33}$.

Calculate L 0.5 marks

7.4.5 The hoisting speed S (m/sec) is given by $0.01486 \times h^{0.5} \times T^{0.4}$ where h is the hoisting (shaft) depth (600m) and T the tonnes hoisted, 5500 mt/day.

Find S 0.5 marks

7.4.6 The hoist motor power H (kW) is given by 7.836 x S x d $^{2.4}$ where S is the hoisting speed (m/sec) and d is the hoist drum diameter (m).

Calculate H in kW. 0.5 marks

7.4.7 The cost of mine development $C_2$ is given by 37033 x T x W $^{-0.8}$ where T is the tonnes/day hoisted (ore only) and W the stope width, W= 10 m.

Find $C_2$. 0.5 marks

7.5 Comment on the efficacy of the parameters chosen to estimate the various values calculated ($D_S$, d, L, S, H) and the eventual cost values $C_{12}$ and $C_2$ you calculated. 1 mark

7.6 Find the cost of the hoist plant given the following cost formulae; 1 mark

Hoist equipment $C_{31}$ = \$ 134261.5 x H $^{0.2}$ x d $^{1.4}$

Hoist installation cost $C_{32}$ = \$ 65437 x d $^{1.8}$

Hoist room cost $C_{33}$ = \$ 25956 x d $^{3.2}$

Head-frame complex $C_{34}$ = \$ 719.67 x L $^{1.8}$ x d $^{1.2}$

Cost Hoist Plant $C_3$ (\$) = $C_{31} + C_{32} + C_{33} + C_{34}$

Comment on the input values making up the total cost of hoist plant $C_3$ and indicate where additional parameters might make estimates more reliable. 1 mark

7.7 Find the cost of the compressor plant by first estimating 'Q' the m3/sec required; 1 mark

Compressed air required in m$^3$/sec Q = 0.0957 x T $^{0.46}$

Cost of compressor equipment $C_{41}$ = \$ 369938 x Q $^{0.8}$

Cost of compressor installation $C_{42}$ = \$ 81382 x Q $^{0.7}$

Total compressor plant cost $C_4$ (\$) = $C_{41} + C_{42}$

Comment on the values of Q which might be expected from a broad selection of underground mines, and how well the total cost $C_4$ estimates the cost of compressor plants. 1 mark

**Question 7 continued**

7.8 The costs of underground mining equipment and an underground maintenance facility are given by the following formulae. Calculate $C_5$ and $C_6$ 1 mark

$C_5$ Cost of Underground Mining Equipment

$$C_5 = 27963 \times W^{-0.3} \times T^{0.8}$$

$C_6$ Cost of Underground Maintenance Facility

$$C_6 = 31945 \times T^{0.5}$$

7.9 Electrical Power, Water, General Plant Services, Access, Town-site and Housing are dependent on location, the milling complex, and fly in-out, town-site or established towns.

Consequently this value is estimated during milling/processing infrastructure cost estimations and can be ignored when estimating underground infrastructure costs. *No calculation or estimate for $C_7$ is required in this exam.*

7.10 Calculate the costs of feasibility and design $C_8$, supervision and camp $C_9$ and administration and accounting etc. $C_{10}$. 1 mark

7.10.1 Feasibility and Design

$$C_8 = 5\% \text{ of } (C_{12} + C_2) + 7\% \text{ of } (C_3 + C_4 + C_5 + C_6)$$

7.10.2 Supervision and Camp

$$C_9 = 9\% \text{ of } (C_{12} + C_2 + C_{31} + C_{32} + C_{33} + C_{34} + C_{41} + C_{42} + C_5 + C_6)$$

7.10.3 Administration, Accounting, Legal, Key Staff

$$C_{10} = 5.5\% \text{ of } (C_{12} + C_2 + C_{31} + C_{32} + C_{33} + C_{34} + C_{41} + C_{42} + C_5 + C_6)$$

7.11 What is the total fixed cost {not including milling/processing and items in 7.9 (mine power, water, housing etc.)} of the initial underground mine. 0.5 mark

7.12 Comment on the reliability and applicability of this methodology for finding the total fixed cost of an underground mine. 2 marks

**End of Exam**