UNISA university of south africa

EXAMINATION PAPER

SUBJECT:	EXAMINER:
CERTIFICATE IN ROCK MECHANICS PAPER 3.4 : OPEN PIT	GLEN MC GAVIGAN
SUBJECT CODE:	**MODERATOR:**
COMRME	PETER TERBRUGGE
EXAMINATION DATE:	**TOTAL MARKS:** [100]
May 2013	**PASS MARK:** 60%
TIME: 9:00 – 12:00	

NUMBER OF PAGES: 6

SPECIAL REQUIREMENTS:

1. **Answer *ALL FIVE* questions**
2. References other than those provided are not permitted.
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 (only the right hand pages will be marked).**
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 that is typical of practical conditions.

QUESTION 1

You are the Principal Geotechnical Engineer for Unobtabium open pit mine, which in the last three years has experienced an increasing number of failures which are linked to geological structures. The root cause of the problem is that the geotechnical and geological department does not map the pit faces and hence the structures cannot be included in the slope designs. You have been instructed by Head Office to address the problem.

You have decided that the best solution is to write a <u>cell mapping</u> procedure (standard operating procedure) which will be rolled down to the geotechnical technicians on the mine. Prepare a standard operating procedure for cell mapping based on the following template:

a. Introduction – to include:

   i. The principle of cell mapping

   Cell mapping only refers to the method of collecting fracture data. Fractures are too numerous to be analysed as single geological structures, and the fracture data are generally analysed by statistical methods. The fracture data are collected by mapping methods that provide appropriate input parameters. Most of the fractures that are measured usually have lengths that are less than the bench height, and the minimum cut off length is usually 0.3 to 1.0m.

   The bench face or outcrop is divided into cells, the width of the cell is equal to about one or two times the height of the cell. Within each cell, the fracture sets are visually identified, and the orientation, length and spacing characteristics are recorded along a line that is orientated in any direction

   ii. Other techniques that can be considered

   <u>Fracture set mapping</u> – fracture sets are visually identified during the course of regular geologic mapping, and the fracture set orientation, length and spacing are recorded.

   <u>Scan line mapping</u> – is a systematic spot sampling method in which the measuring tape is stretched along the bench or outcrop to be

measured. For all of the fractures along the tape, the point intersection with the tape, orientation, length roughness, fill type and thickness are recorded.

b. Definitions must include:

i. geological structure

Are all fractures and major structures, regardless of length

ii. fractures/joints

Are geologic structures that break the intact rock into more discrete blocks. The usually comprise the rock fabric and sometimes the intermediate structures. The fractures and joints are generally too numerous to be and too short to be individually mapped throughout the deposit

iii. major structures

Are geologic structures such as faults, shears, folds that are large enough to me mapped and located as individual structures. There is a continuum between fractures and major structures. The lower length truncation limit can vary, but in general it is equal to the height of a single bench design.

iv. rock fabric

Defined as geologic structures which are too numerous to be evaluated individually. They are therefore treated as statistically in the slope analysis. The rock fabric may include both fractures and major structures.

v. intermediate structures,

Defined as geologic structures which are too numerous to be evaluated individually and are treated statically in the slope design. The intermediate structures only include major structures that are longer that a given, lower length truncation limit. The lower length truncation limit is generally equal to or greater than the height of 2 benches.

vi. regional structures, and

Major structures of regional scale. Generally has a minimal length of 100m, when these structures are faults, they are usually uniquely identifiable on geological maps.

vii. structural domains.

Are zones which the distribution, orientation, length, spacing and shear strength, etc. are similar.

c. Safety considerations while cell mapping.

- Should be conducted by at least 2 persons. The second person should fulfil the role of data collector and spotter spotter.
- Time at the face should be kept to an absolute minimum.
- Risk assessment and rock fall assessment should be conducted before the commencement of the activity.
- No mapping to be performed if there is flowing water, active dust trails, audible rock noise, ejection etc.
- No mapping directly after blasting or after periods of rainfall.
- Risk mitigation measures may include:
  - Rock fall protection e.g. cages or coverage by truck bowl parked against high wall.
  - Use of remote techniques to collect orientation data e.g. Photogrametry (Sirovision, Shapemetrix), Laser (IBIS) etc.

d. Cell mapping procedure (step by step guide, including data to be collected)

The bench face should be divided into zones of equal length, called cells. Cells are usually square with the width of each cell equal to the height of the bench. Depending on the time and resources available 2 forms of cell mapping can be done:

1. Entire benches mapped with contiguous cells
2. Mapping string of contiguous cells, from 2 – 3 contiguous cells to as many as 10 or more, located in different parts of the study area.

Typical data to be collected:

Cell:

- Cell number
- Cell width and height
- Rock type
- Face strike and dip
- Survey control
- Remarks

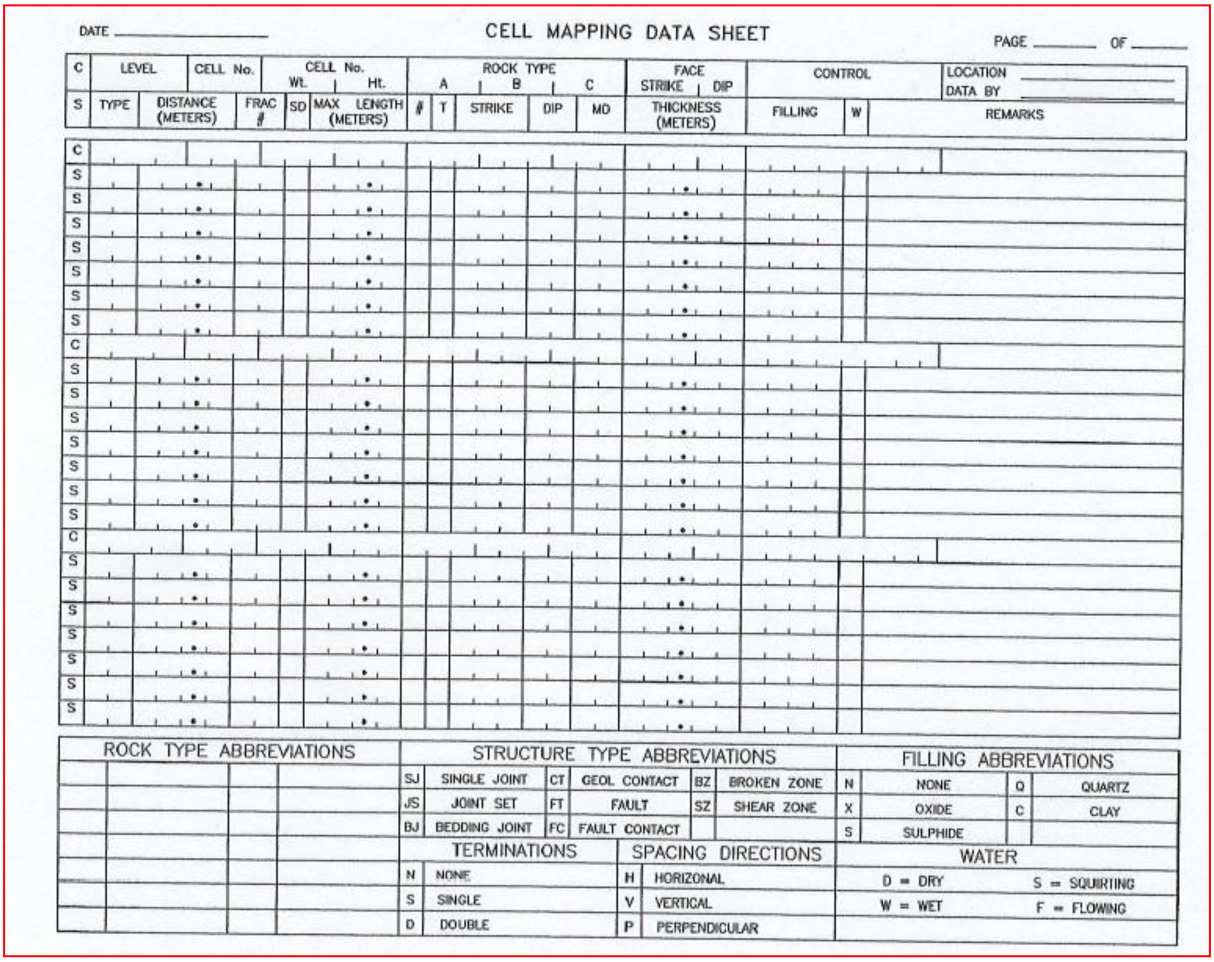
Structure:

- Type: joint, bedding, facture, shear, faults etc
- Distance – distance over which the number of fractures in the structure set is counted.
- Number of fractures – per set recoreded

- Spacing direction – direction, in the physical sense, in whcih the fracture count or spacing is measured. It is measured as either vertical, horizontal, perpendicular or true.
- Maximum length – this is the greatest observed trace length of a fracture or structure within a set.
- Number of fractures of maximum length
- Termination: type of termination of the longest fracture in a set. Can be doubly terminated, singly terminated or no termination
- Strike
- Dip
- Fracture fill:
- Water e.g Dry, flowing, wet
- Remarks

e. Cell mapping data sheet

Example of a cell mapping data sheet.



DATE ______ CELL MAPPING DATA SHEET PAGE ____ OF ____

C	LEVEL	CELL No.	CELL No. Wt. Ht.	ROCK TYPE A B C	FACE STRIKE DIP	CONTROL	LOCATION / DATA BY
S	TYPE	DISTANCE (METERS)	FRAC #	SD	MAX LENGTH (METERS)	#	T	STRIKE	DIP	MD	THICKNESS (METERS)	FILLING	W	REMARKS

ROCK TYPE ABBREVIATIONS

STRUCTURE TYPE ABBREVIATIONS

SJ	SINGLE JOINT	CT	GEOL CONTACT
BZ	BROKEN ZONE	JS	JOINT SET
FT	FAULT	SZ	SHEAR ZONE
BJ	BEDDING JOINT	FC	FAULT CONTACT

FILLING ABBREVIATIONS

N	NONE	Q	QUARTZ
X	OXIDE	C	CLAY
S	SULPHIDE		

TERMINATIONS

N	NONE
S	SINGLE
D	DOUBLE

SPACING DIRECTIONS

H	HORIZONTAL
V	VERTICAL
P	PERPENDICULAR

WATER

D = DRY	S = SQUIRTING
W = WET	F = FLOWING

f. Data interpretation and further processing

Data should be analysed in Schmidt plots (steronets) in order to identify zones of similar structural orientation. These can then be used to identify potential failure mechanisms based on the orientation of the slope/bench. The various joint sets should be characterised not only in terms of orientation but spacing, length, fill etc.

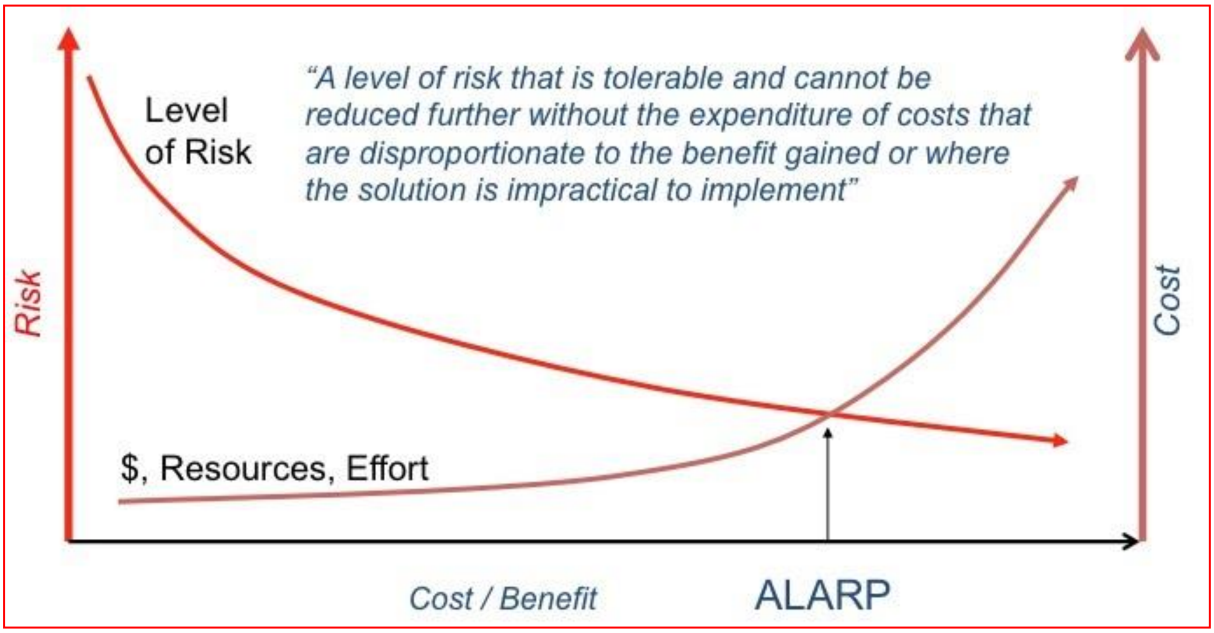
The data can be further used to determine rock mass classification and fracture models for inclusion in limit equilibrium and numerical models.

[20 MARKS]

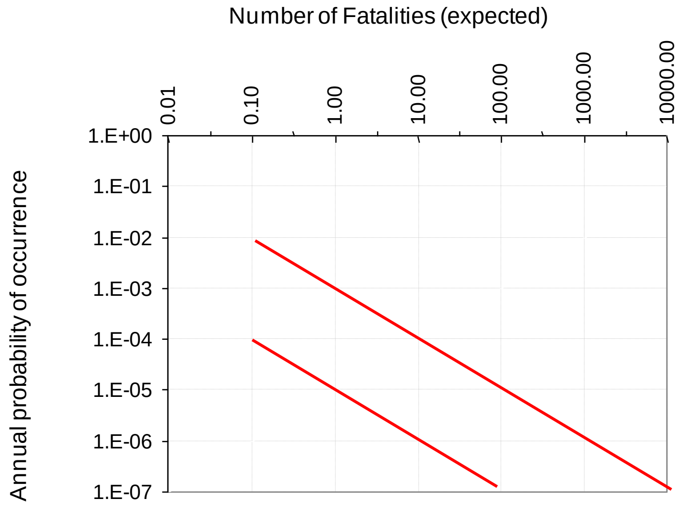
QUESTION 2

Define and discuss the following (use sketches and diagrams where possible/applicable):

a. As Low as Reasonably Practicable (ALARP) [4]



Typical FN chart showing ALARP region



ALARP 1:1000 – 1:100000

1 to 1:10 -	Intolerable
1:10 to 1:100 -	Justifiable
< 1:10000 -	Negligible

b. In terms of numerical modelling, define and discuss the following:

i. Ubiquitous joint model [3]

Ubiquitous joints model – joints can occur at any location in the rock mass but of a specified orientation and stiffness. The ubiquitous joint model is often used to simulate anisotropy.

ii. Strain softening model [3]

Is the modeled stress strain response in which the shear resistance falls from its peak value to a lower value with increasing shear strain. This is a non linear model.

iii. Boundary conditions [5]

Boundaries are either real or artificial. Real boundaries in the slope-stability problems are the natural or excavated ground surfaces. All problems in geomechanics require that the infinite extent of a real problem domain is truncated to include only the area of interest.

Artificial boundaries can either be prescribed displacement (either in the x or y or both directions) of prescribed stress.

A fixed boundary causes both stress and displacement to be underestimated, whereas a stress boundary has the opposite effect.

c. Back Analysis [5]

[20 MARKS]

QUESTION 3

It is the year ***1962*** and you are the newly appointed geotechnical engineer for a large open pit operation in the tropical regions of central Africa. The following information has been supplied by the previous geotechnical engineer prior to fleeing the country following a series of large undetected failures:

- Pit is rectangular in shape and with its long axis orientated NE-SW
- There is a single access ramp into the pit.
- Pit depth – 500m
- Overall slope angle - 42 deg
- Bench height 15m
- Bench face angle – 80 deg
- Stack height - 60m
- Stack angle - 55 deg
- Upper 50m of the slope will be constructed in highly weathered material
- Remainder of the rock mass has an average RMR of 67 and may be regarded as brittle.
- The average joint spacing is 20cm
- Several large scale faults pass closely behind the pit slope and it is believed that smaller sympathetic faults may daylight in the slope.
- Several large wedges were identified from orientated core and stereographic analysis
- The pit is situated in an active rift valley.
- Annual rain fall of 2500mm with over 200 days of rain per year
- Dense fog is experienced in the early morning during the winter months
- On average it takes 12 days travel to site from Johannesburg.

a. Devise a monitoring strategy for the pit and pay particular attention to the failure mode, expected movements and system accuracies. Detail at least three methods that you would use to monitor the pit. List the advantages and disadvantages of each of the methods that you describe. NB, it is 1962. [15]
No radar or GPS methods are available it is 1962.

The conditions to be monitored vary from soft rock (large deformations over time) to brittle rock (small deformations over a short time) and therefore need to cater for both situations. A typical set up could be:

- Survey prism monitoring with theodolite. Prisms should be systematically installed and densified on critical wedges and on main access into the pit.
    - Advantages – accurate, long term.
    - Disadvantages – manual, discrete points (considering 20cm average joint spacing), prisms difficult to maintain and install. May be affected by the fog. Atmospheric effects are likely to be high considering temperature and humidity variations; therefore it may only be possible to compare readings of the same time of day with each other.
- A series of inclinometers should be installed on critical Geotech domains to monitor large structures etc. Data may be linked remotely.
    - Adv – very accurate, gives information on the rock mass and specific structures.
    - Diadvantages – single point, if existing holes are not used costs of drilling dedicated holes are high.
- Extensiometers should be installed and access maintained (typically on creast, accessable benches and haul roads), these can be linked to audible alarms.
    - Advantages: cheap, easy to install, mobile, can be measured by lower qualified workers.
    - Diadvantages: single point, not three dimensional.
- Visual inspections – a systematic visual inspection program is required. The visual inspections should be carried out be personnel trained in the identification of rock related hazards ranging from foremen to geotechnical engineers. Standard forms and procedures should be developed to ensure consistency in visual monitoring.
- Seismic monitoring (geophones) should be installed considering the mine is in a rift valley.
- Rainfall and groundwater monitoring – considering the blockiness of the rock mass, rock falls may occur after and during heavy rainfall. The monitoring of the intensity of rainfall linked to a TARP is good practice. Because of the high rainfall groundwater recharge is likely to be high and should be monitored with piezometers.
- Technicians must be trained in the maintenance of the equipment as it takes 12 days to travel from Johannesburg. Critical spares should be kept on site.

- Considering the high occurrence of fog and the reliance on optical methods of monitoring (e.g. visual and prism) the mines risk management plans should be updated to address the risk of not being able to adequately during fod days. Alternatively the monitoring procedure (prism) could be modified for this period to collect data in the afternoon when the fog is less of a problem.

b. Based on your strategy, devise a Trigger Action Response Plan (TARP) for at least two of your monitoring methods. [10]

A TARP is management plan that includes a set of responses to a likely event. Your answer should discuss the triggers and responses for each system.

- Trigger – what is the threshold of measurement that will trigger the activation of the management plan. Discuss typical thresholds in terms of amount of "movement" and frequency. Discuss the various thresholds e.g, green, orange and red.
- Action and response – what actions must take place for each of the thresholds (e.g. green, orange and red)? Important to include who the responsible and accountable personnel for each trigger. This should include – mine manager, pit managers, safety dept, snr geotechical, geotechnical engineers and all impacted personnel.

[25 MARKS]

QUESTION 4

The Omnisham feasibility study into a new Unobtanium mine off the coast of Utopia has concluded that the project has an NPV of R70,000,000; this is however considered to be unattractive to the shareholders and potential investors. All of the technical specialists have been requested to revisit the pre-feasibility study and indentify opportunities for optimisation and cost reduction (in the potential operating mine) in order to make the project more economically attractive.

Discuss how you as a geotechnical engineer can contribute to making the project more economically attractive. Be sure to focus on <u>all aspects of the mining value chain</u> where geotechnical data may be applied. In giving your answer be clear to mine management about the risks and rewards of each of your suggestions.

Geotechncial data can be used through the whole value chain to improve the economics of the project. The following could be considered to increase the value of the operation:

- Increase slope angles thereby reducing waste stripping and/or resulting in the extraction of additional ore. The increase in slope angle will result in an increase in the probability of failure and you should highlight this to management. You should discuss what risk management places that could be put in place to manage the risk e.g:

- Extensive monitoring to reduce the safety risk of failure to personnel
- Additional stockpile or exposed ore may be required to buffer the potential for a slope failure and therefore reduce the risk to the mine plan.
- Additional access ramps may be required
- Additional geological and geotechnical data may be required
- If the slopes are wet, dewatering and/or depressurising measures may be required.
- Pre-split, trim and buffer blasting may be required or modifications required

- Fragmentation – routinely collected geotechnical data (rock mass classification, UCS, tensile strength etc) can be used to optimise the fragmentation during blasting resulting greater mill/crusher throughput and improved loading rates. This can be beneficial in terms of the specification of the crusher as well as the amount of drill, load and haul equipment required. This data should be collated in the form of a geotechnical block model which will enable the optimisation of the mine plan based on fragmentation.

- Drill and blast optimisation – the drilling pattern and explosive requirements can be optimised if the designs are based on geotechnical data. It is critical however that any increase in burden and spacing does not negatively impact on the fragmentation ore or waste.

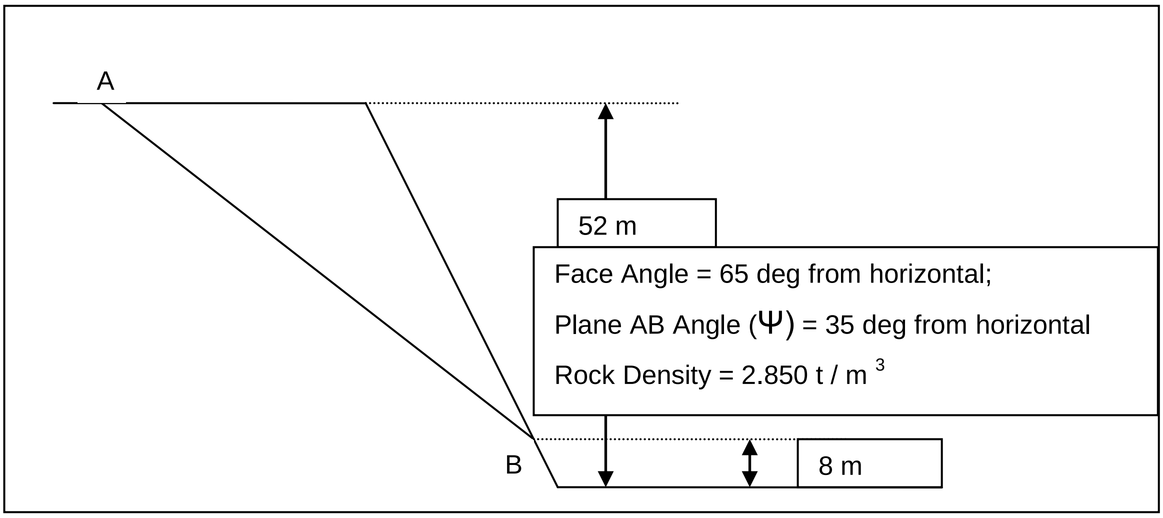
Any of the above should be discussed in terms of benefit and the risk it poses to the operation. The incremental increase in NPV (which should take account of the increased risk) as a result of slope steepening, better fragmentation and optimised drill and blast should be quantified and presented to management. The decision to proceed with any of the initiative depends on the increase in value and the risk appetite of the operation.

[15 MARKS]

QUESTION 5

Figure 1 illustrates the geometry of a potential planar slope failure which contains a talc filled fault (AB). The slope is regarded to be dry.

Figure 1



You have requested that ten shear strength tests be performed on the plane. Dr Jen from Pick n' Lab performed the test and the table below summarise the results.

	n	Mean	Std Deviation	Coefficient of Variation
Cohesion (MPa)	10	0.0153	0.0031	20%
Friction (deg)	10	16.8	1.48	8%

Note: the distributions of the random variables can be regarded as truncated normal with the cohesion ranging from the mean by +33% and -34.4% and the friction angle by +15.3% and -16.8%.

The General Manager of the mine is pressurising you for an answer as production has been suspended until such time as you have completed your stability assessment.

Using the formulas provided calculate:

a. The factor of safety at the average values for cohesion and friction.

b. The probability of failure of the slope using Harr's point estimate method with the distributions provided.

List any other assumptions you have to make, comment on the results obtained and make a recommendation to the General Manager.

Formulae

Factor of Safety

$F = (cA + (W\cos\beta)\tan\Phi) / W\sin\beta$

Point Estimate Method Formulation.

$P_F = \sum F / (1 - \text{std dev } F)$ where F is derived for the values of the distributions of c and Φ.

$\sigma^2_F = \underline{F^2} - (\underline{F})^2$

Solution

A = L x B

= 44/sin25

= **76.7m**

$W = (Y_w H^2)/2 \times (\cot \Psi p - \cot \Psi f)$

$= (2.85 \times 44^2)/2 \times (\cot 35 - \cot 65)$

= **28.174MN**

F = (cA + (Wcosβ)tan Φ) / Wsinβ

= (0.053(76.7) + (28.174cos35) x tan16.8) / (28.174sin35)

= 0.538

For point estimate method:

Number of permutations = $P_n^k = 2^2 = 4$

Weighting factor $(1/2)^2$ = ¼, it is assumed that there is no correlation between the variables.

PEM method						
Permutations	**c**	**phi**	**F**	**F/4**	**F^2**	**F^2/4**
++	0.0184	18.28	0.559106	0.139777	0.3126	0.07815
- -	0.0122	15.53	0.454779	0.113695	0.206824	0.051706
- +	0.0122	18.28	0.529675	0.132419	0.280556	0.070139
+ -	0.0184	15.52	0.483942	0.120985	0.2342	0.05855
			F	**0.506875**	**F^2**	**0.258545**
			sig^2	= F^2 - (F)^2		
				0.001622		
			sig	0.040274		

Pof 100%

[20 MARKS]

[100 MARKS]