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Group Code (if applicable): 4 (Tutorial 6)

Assignment Title:	Assignment 2.
Subject Number:	CVEN 30008
Subject Name:	Engineering Risk Analysis.
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Due Date:	May 16, 2016.

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CVEN 30008 Engineering Risk Analysis

Assignment 2- Quantitative Risk Analysis

Risk Analysis of slope failure in the Mining Industry

Report on Quantitative Risk Assessment

Document Status:

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Table of Contents

1. Introduction and Purpose

Mining sectors play an important role in Australian industries. Mining industries also contribute significantly to economic development of Australia. ABC Open Pit Mines (ABC) owned by Travis Gold Mining are employed to extract the minerals near the surface. In order to minimize excavation cost, steeper slope angles are found and implemented on site. However, It is important to minimize risks such as injuries, environmental damages, unexpected and extra costs. Therefore, identifying the risk factors existed on site is necessary. A recently excavated slope named Blue slope and a slope excavated last year named Yellow slope are investigated and analyzed by geotechnical team to achieve best solutions. The aim of this report is to identify risk factors of two investigated slopes as well as to implement quantitative analysis of slopes for probability of failure. Preferable risk treatment options will also be suggested in this report to reduce risks.

2. Executive Summary

This report describes the risk analysis done by a team from ABC for the excavation of the Blue slope and its subsequent management as well as the management of the Yellow slope which was excavated 1 year ago (see photograph below).

The critical risk factors were found to be: the angle of the slopes; the type of rock nature of faults; the potential damage caused by a failure; applied loads; vibrations from excavation of the Blue slope; weather-induced erosion.

Using the experimental data provided for the angle of friction (ϕ) which had a mean of 48.9^0 and a sample size of 50, the mean ϕ for the whole slope was estimated to be less than 53^0 with a confidence level of more than 99% using Z-score analysis.

A Monte Carlo simulation was then run for 20^0 < slope angle < 70^0 and the assumptions on clean-up and excavation costs (see sections 4.1.4 and 4.2.2) to calculate the probability of failure (PoF) which was found to be strongly positively related (correlation coefficient = 0.9876).

The recommended slope angle was found to be 50^0 as it had the lowest combined excavation and clean-up cost. Other recommendations were: to monitor the size of cracks and the displacement of rock masses; minimise applied forces on the slopes; pay attention to the weather forecast; ensure workers have adequate protective gear; minimise all types of pollution.

3. Identification of risk factors

The most critical risk factors for a slope are:

- **The angle of the slope** - steeper slopes are more unstable since there is less friction between planes of rock and more mass to support (DNR, 2015).
- **The material of the slope** - the strength of the rock and the degree of cracking significantly affects its stability, this can change over time so it is important to take this into account. Any layering of materials such as an extensive crack in the rock, a vein of weaker material or the inherent structure of sedimentary rocks can result in weaker areas of the slope (Girard, 2012).
- **Location** - any applied loads near the edge of a slope such as stationary mining equipment or moving vehicles can create additional downwards pressure which can destabilise an otherwise stable slope. The consequences of a failure of a slope with expensive equipment or people working below are greater than the failure of a less critical slope. There appears to be a road both above and below both the Blue and Yellow slopes meaning their failure could have significant consequences.

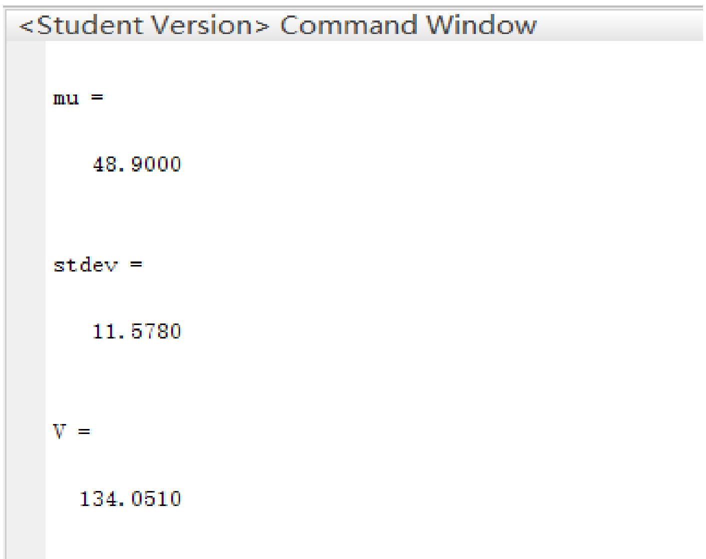
- **Vibrations** from nearby drilling or blasting can cause problems to existing slopes by increasing the length of cracks (Oriard, 1972). Even though the Blue slope is above the Yellow slope, its excavation could have weakened the Yellow slope.
- **Erosion** - Weather events such as heavy rain or the freeze-thaw cycle can have a significant effect on the stability of a slope by increasing cracking (Hormazabal & Rovira, 2009). The longer a slop has been exposed, the greater the degree of weathering, this can be reduced by draining and diverting water away from the slope. The Yellow slope has been excavated for a year and would have experienced some erosion which may result in loose material falling away.
- **Pollution** - Air, noise and soil pollution can put the company at risk of expensive financial penalties.

4. Quantitative risk analysis

4.1 Blue Slope

4.1.1 Descriptive Statistics Summary:

By using the given data of the test results from blue slope, the descriptive statistics of the friction angle are obtained by Matlab in the following screenshot. The distribution of the friction angle is normal distribution.



```
<Student Version> Command Window

mu =

   48.9000


stdev =

   11.5780


V =

  134.0510
```

Figure 1: screenshot of descriptive statistics(Matlab)

In the screenshot, mu (μ) = 48.9 is the mean of the friction angle (ϕ) of the samples, stdev = 11.5780 is the standard deviation, and V = 134.0510 is the variance

4.1.2 99% Confidence Interval:

Since the sample size N = 50 > 30, μ = 48.9, stdev = 11.578, the sample size is large enough to use Z-score to evaluate the friction angle with 99% confidence interval. So $\alpha = 1 - 99\% = 0.01$ and $\alpha/2 = 0.005$, $Z_{\alpha/2} = -2.575$ (By using standard normal cumulative probability table).

$\mu = X \pm Z_{\alpha/2} \times (S / \sqrt{n}) = \mu \pm Z_{\alpha/2} *(\text{stdev} / \sqrt{n}) = 48.9 \pm 2.575 \times (11.578/ \sqrt{50})$

$\mu = 44.68$ or $53.12 \rightarrow 44.68 < \mu < 53.12$

Matlab results:

```
Z_alphaon2 =

   -2.5758


CI =

   44.6824   53.1176
```

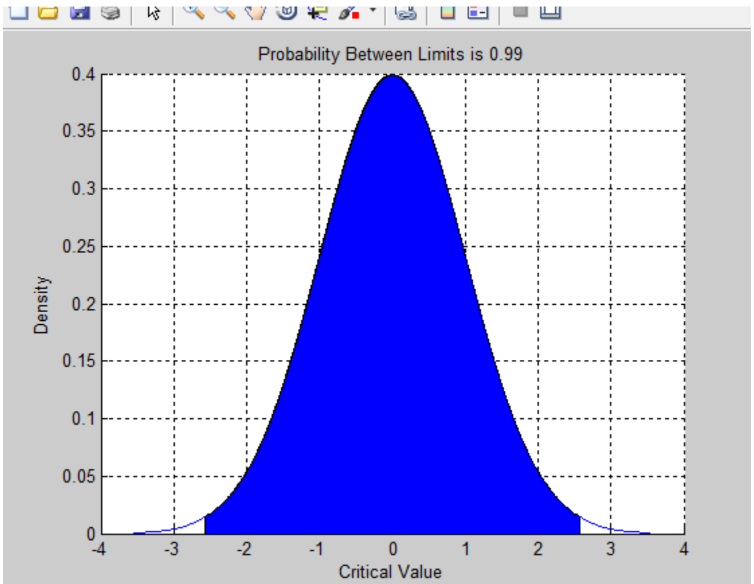


Figure 1.2: screenshot of 99% interval (Matlab)

4.13 Hypothesis Test:

In this part, hypothesis test is used to check whether the mean of the friction angle is less than 53^0. We can assume: H_0: $\mu \geq 53$ and H_1: $\mu < 53$. As well as this, we have already obtained n = 50, $\mu_0 = 53$, $\mu = 48.9$ and stdev = 11.578. As a result, P-value is able to be calculated by using Z-score table.

$Z = (X-\mu_0) / (S / \sqrt{n}) = (\mu - 53) / (stdev / \sqrt{n}) = (48.9 - 53) / (11.578 / \sqrt{50}) = \mathbf{-2.50}$

So P = 0.0062 (From standard normal cumulative probability table)

Since $\alpha = 5\% = 0.05$ and $P = 0.0062 < 0.05 = \alpha$, P-value is smaller than 5%. This indicates that H_0 should be rejected. Therefore, the mean of the friction angle is less than 53^0 and the engineer's hypothesis is true.

Matlab results for hypothesis test:

<Student Version> Command Window

```
Left tail test

p =

    0.0061

Since p <= alpha, Reject H_0
```

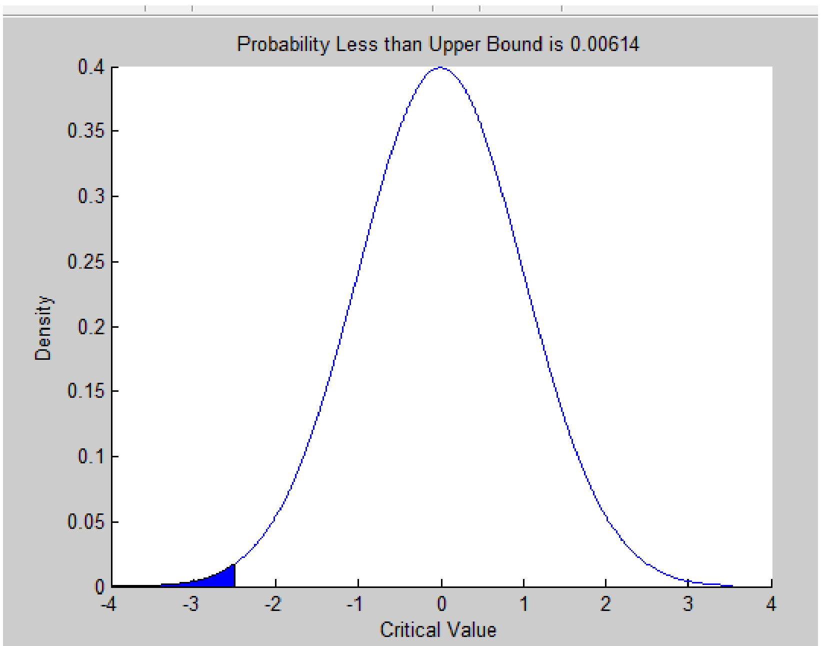


Figure 1.3: screenshot of hypothesis test(Matlab)

4.1.4 Monte Carlo Simulation:

Monte Carlo simulation is used to evaluate the Probability of Failure (PoF) and obtain the histogram for Factor of Safety (FoS). FoS = tan ϕ/tan β, where β is angle of sliding plane = 40^0 (given). PoF is the probability when FoS is less than 1. Some important information is also given (failed rock volume is 200,000 m^3 and cleanup cost is \$100/m^3). Our seed number is **610**.

Matlab simulation:

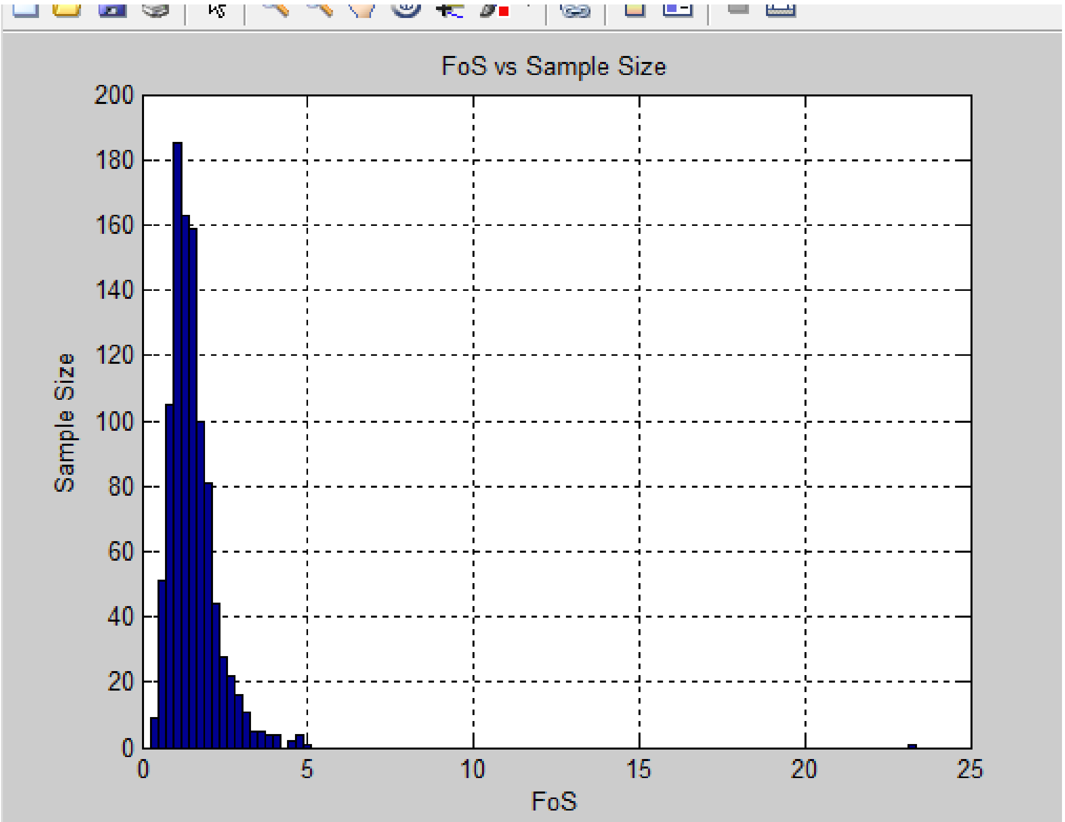


Figure 1.4: Histogram for Factor of Safety (FoS) (Matlab)

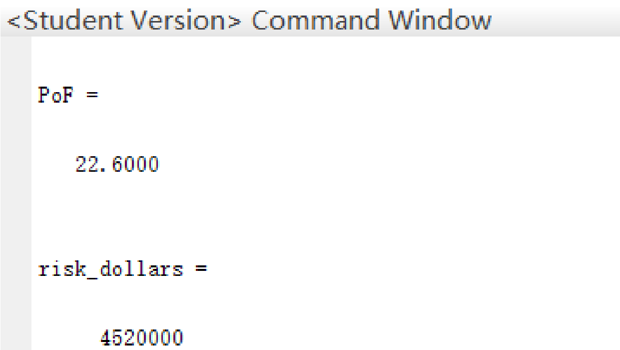


Figure 1.5: screenshot of PoF and failure in dollars (Matlab)

Therefore, by using Matlab, we find that PoF is 22.6% and the total cleanup cost is $4,520,000.

4.2 Yellow Slope

4.2.1 Linear regression

Sample correlation coefficient: r = 0.9876

Therefore, it suggests that there is a strong positive correlation between slope angle (γ) and probability of failure (PoF).

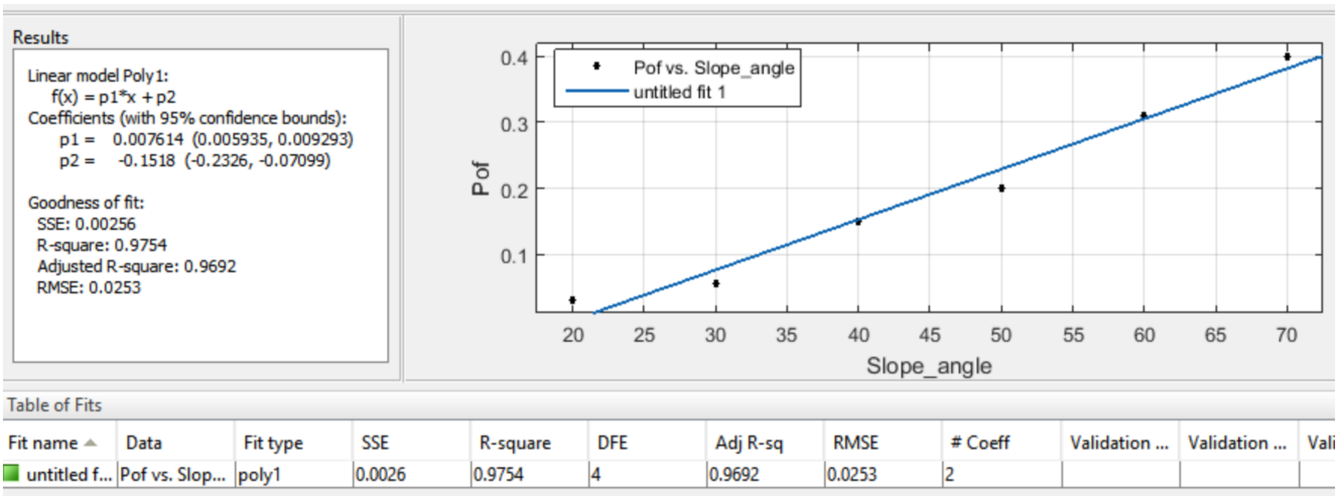


Figure 2. Least square line graph calculations from Matlab

From Figure 2, the least square line for predicting probability of failure (PoF) from slope angle (γ) is

$$\mathrm{PoF} = (0.0076 \times \gamma) - 0.15$$

4.2.2 Excavation cost

The Yellow Slope is originally at 70 °slope angle. It costs $150,000 per degree to excavate.

Excavation cost is calculated as follows.

Excavation cost = (70 – new slope angle) x $150,000

The results are summarized below:

Slope angle	Excavation Cost ($1000)
20	7500
25	6750
30	6000
35	5250
40	4500
45	3750
50	3000
55	2250
60	1500
65	750
70	0

Table 1: Slope excavation cost with respect to slope angles

4.2.3 Risk of failure

Probability of failure ($) is calculated by multiplying Probability of Failure with slope failure cost ($17,500,000). The results are summarized as follow.

Slope angle (degrees)	Probability of failure	Probability of failure ($)
20	0.03	525000
25	0.0425	744000
30	0.055	963000
35	0.1025	1794000
40	0.15	2625000
45	0.175	3063000
50	0.2	3500000
55	0.255	4463000
60	0.31	5425000
65	0.355	6213000
70	0.4	7000000

Table 2: Probability of failure ($) of respective slope angles

4.2.4 Recommendation of optimal value

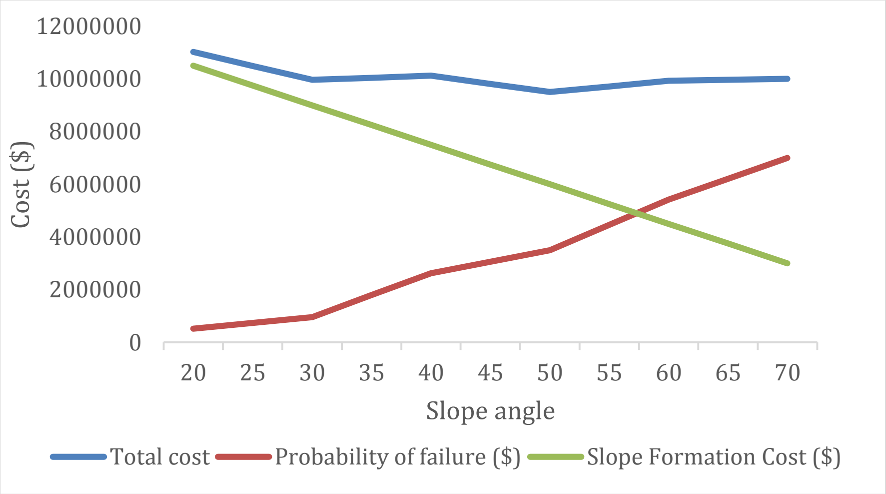


Figure 2.1 Cost benefit Chart

Total cost = Excavation cost + Probability of failure ($)

Slope angle (degrees)	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**
Total cost ($1000)	8025	7494	6963	7044	7125	6813	6500	6713	6925	6963	7000

Table 3: Total cost of the respective slope angles

From Table 3, it can be seen that the lowest total cost is $6.5m. Therefore, the slope angle of 50 °is recommended for the Yellow Slope.

5. Risk treatments and proposed implementation

Some critical risks stated before regarding to environment, safety and cost could be managed by applying several treatments, ongoing monitoring and plan reviews. Environmental problems, safety problems and cost problems are linked together. In this case, the typical treatments required the most is by considering these three issues simultaneously.

5.1 Environmental risk treatment

Firstly, the mining activity and its workspace could be affected by bad weather conditions, such as strong wind, flood and heavy fog. The ongoing treatment to minimize the risk of weathering is to follow the weather forecasting. Moreover, observation on the ground condition is also necessary as it will give an estimation of the rock failure time due to weather.

Secondly, the equipment and materials that are used in the project should be suitable for the climate and soil environment and could be more environmental-friendly. For example, the equipment may be designed to avoid erosion by climate, and cause less noise pollution. In addition, manager should consider that the investment in equipment and materials is worth or not. Air pollution such as dust might be reduced by increasing the efficiency and reduce the work time.

Finally, flora, fauna and soil play important roles in ecosystem. In order to protect the fauna, soil and flora, the company should collect useful information about the vegetation types, soil types and fauna types before the project start. Besides this, some chemical test on the site should be made, such as pH value testing and sample gas detection.

5.2 Safety treatment

There are three main treatments for workers' safety. Firstly, failure of slope needs to be avoided to reduce the likelihood of this risk. The professional engineers should analyze the rock shear strength, surface roughness of rock before the project starts to make sure that the slope was in a safe condition, and other conditions such as climate and soil characteristics should be considered for slopes. Besides slope failure, better safety suits should be developed and worn as regulation in the site. Safety equipment includes helmets, illumination, work boots, safety glasses, high-visibility jackets, work gloves and these are necessary for workers' safety. Gas detector should be posted at mining venues to warn workers if toxic gas leakage. Hazard signs should be put in the project site clearly and make sure they are visible. The company managers should check the safety equipment on time to make sure workers in a safety condition. Furthermore, the company should hire the workers who have professional safety knowledge. They can protect them in a higher level and this could help the company decrease the safety cost.

5.3 Cost treatment

Company should always estimate the budget required for a certain period of time. Company cannot set a fix budget for the project, because budget always changes with the real project cost. However, reducing the costs on excavating soil typically would increase the risks of safety. Workers' health should be monitored at a high level to make sure that they are fit for the working condition and this would help the company avoid unwanted casualties and save money. The company should only pay attention to minerals or materials that the society demands to prevent stocking of goods when they excavate. This would help them increase their revenue. Implement time limits for each phase to ensure that the project is not behind the schedule.

6. Findings and Recommendations

Through the research and analysis of the blue slope and yellow slope, there are 5 critical risk factors existed potentially during the excavation of slope. The angle and material of the slope generally affect the stability of the slope. The steeper slope reducing the friction, high degree of crack, weaker material will lead to failure of slope. On-site events such as moving vehicles, drillings also impose the additional pressure and vibration that may affect the failure of slope. Weathering and erosion caused by rain and natural processes will reduce the strength of the slope and increase cracking. Yellow slope may experience more erosion as it has already been exposed for 1 year. After the analysis of two slopes using Monte Carlo Simulation and linear regression, the frictional angle for blue slope is less than 53 °which is consistent with the hypothesis of engineer. The cleanup cost is $4,520,000. Similarly, the optimal slope angle of yellow slope is 50 °and total $6,500,000 will be cost if the slope is failed.

There are some recommendation listed below:

1. Environmental risk treatment such as weather forecasting, chemical treatment, environmental- friendly equipment and protection of biodiversity have to be considered.
2. Factors such as shear strength and roughness of rock are required to be analysed before excavation. Safety equipments and proper training are suggested.
3. Financial budget estimation is necessary to be done before construction. Ongoing supervision and protection are implemented to ensure the safety and reduce the unexpected cost.

References

DNR, 2015. *What Are Landslides And How Do They Occur?.* [Online] Available at: http://file.dnr.wa.gov/publications/ger_fs_landslide_processes.pdf [Accessed 13 May 2016].

Girard, 2012. *ASSESSING AND MONITORING OPEN PIT MINE HIGHWALLS,* Spokane: Centers for Disease Control and Prevention.

Hormazabal & Rovira, 2009. *Analysis and design of slopes for Rajo Sur, an open pit mine next to the subsidence crater of El Teniente mine in Chile,* Santiago: SRK Australia.

Oriard, 1972. *Blasting Effects and Their Control in Open Pit Mines in Geotechnical Practice for Stability in Open Pit Mining.* Denver, International Conference on Slope Stability in Open Pit Mining.

Appendix

Matlab codes:

```
clear all;
close all;
clc

data=[47 37 52 63 62 67 28 48 61 40 43 33 32 40 42 29 44 46 51 45 47 46 63 49 48 45 70 59 73 43 67 34 55 59 69 49 45 57 45 58 36 42 35 46 50 50 47 72 33
mu = mean(data);          % sample mean (normally distributed)
stdev = std(data);        % sample standard deviation
V=stdev^2;                 % sample variance
display(mu)
display(stdev)
display(V)

N = 50;                    % sample size
stderror = stdev/sqrt(N); % sample standard error
alpha = 0.01;
alphaon2 = alpha/2;
Z_alphaon2 = norminv(alphaon2);
display(Z_alphaon2);
normspec([norminv(alphaon2) -norminv(alphaon2)],0,1);
grid on;
CI = [mu+Z_alphaon2*stderror, mu-Z_alphaon2*stderror];
display(CI);               % calculate interval
```

Figure 3: Matlab codes for section 4.11 and 4.12

```
clear all;
clc;

data=[47 37 52 63 62 67 28 48 61 40 43 33 32 40 42 29 44 46 51 45 47 46 63 49 48 45 70 59 73 43 67 34 55 59 69 49 45 57 45 58 36 42 35 46 50 50

N = 50;          %sample size
x_bar = mean(data);    %sample mean
mu_0 = 53;       %test mean
S = std(data); %sample standard deviation
stderror = S/sqrt(N);
z = (x_bar-mu_0)/stderror;

side = 'left';

if strcmp(side,'both')
    display('Two tailed test');
    display('Graph is showing one side instead of two-sided, hence it is showing p/2');
    normspec([-inf -abs(z)],0,1);
    p = 2*normcdf(-abs(z));
elseif strcmp(side,'left')
    display('Left tail test');
    normspec([-inf -abs(z)],0,1);
    p = normcdf(-abs(z));
else
    display('Right tail test');
    normspec([abs(z) inf],0,1);
    p = 1-normcdf(abs(z));
end

display(p)

alpha = 0.05;

if p > alpha
    display(p);
    display(alpha);
    display('Since p > alpha, Do not reject H_0');
else
    display('Since p <= alpha, Reject H_0');
end
```

Figure 4: Matlab codes for section 4.13

```
clear all;
close all;
clc;

data=[47 37 52 63 62 67 28 48 61 40 43 33 32 40 42 29 44 46 51 45 47 46 63 49 48 45 70 59 73 43 67 34 55 59 69

rng(610)                    % seed number
mu = mean(data);            % sample mean (normally distributed)
sigma = std(data);          % sample standard deviation
size = 1000;                %sample size

r= mu+sigma.*randn(size,1);
n= length(r);

for k= 1:n
    FoS(k)=tand(r(k))/tand(40); %beta=40
end
hist(FoS,100);     %plot histogram, bins=100
title('FoS vs Sample Size')
xlabel('FoS');
ylabel('Sample Size');
grid on;

allowable_FoS = 1;
counter = 0;
for j= 1:n
    if FoS(j)<allowable_FoS;
        counter=counter+1;
    end
end
PoF=counter/size*100;
display(PoF);
%cost = $100/m3    volume = 200000m3
risk_dollars=PoF/100*200000*100;
display(risk_dollars)
```

Figure 5: Matlab codes for section 4.14

- Matlab Calculation for Regression test and Least square line

```
% regression test
   % Engineering Risk assessment
   % Tutorial 6, Group 4
clear all;
close all;
clc;

Slope_angle= [70 60 50 40 30 20];
Pof= [0.4 0.31 0.2 0.15 0.055 0.03];

%correlation between Slop_angle and Pof

r_tmp=corrcoef(Slope_angle,Pof);
r= r_tmp(1,2);

display('Correlation coefficient for Slope_angle vs Pof:');
display(r);
display('suggests a strong positive correlation relationship between Slope-angle and Pof.');
fprintf('\n')

%Least Square Line
cftool;
```