Risk Analysis of Lifeline Infrastructures Threaten By Landslide

By

Ummi Anisah binti Norhaidi

19065

Dissertation submitted in partial fulfilment of the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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(Assoc. Prof. Dr Indra Sati Hamonangan Harahap)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

September 2017

CERTIFICATION OF ORIGINALITY

This is to hereby certify that this submission is my own work under my own responsibility, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted by the university or any other educational institution except where due acknowledgment is made in the thesis. Any contribution made by colleagues throughout the research whom I have worked with is fully acknowledged.

UMMI ANISAH NORHAIDI

ABSTRACT

Landslide in general a movement of a soil mass due to specific mechanics of slope failure. The factors triggering landslide could be natural causes or it could also be under the influence of human activities. Different landslide types contributes to different types of effects to property, injury and even death. Commonly effects of landslide in Malaysia are fatalities, serious injuries and infrastructure and structure destruction. The major part to be considered is the restoration activities that will be done after the occurrence of the natural events. Restoration activities could be costly and it will also impacts the economy of a country. The occurrence of landslide could not be stop. However, preventive way could be considered, by analyzing the stability of the slope. It is important to be able to analyses a slope whether it is stable by using a reliable method that considers all factors which are the forces acting on the slope. Therefore, this research study will be focusing on analyzing on slope stability by using limit equilibrium method to compute Factor of Safety on a slope. This will be done by the assistant of MATLAB coding. To ensure the objectives of the research is achieved, a case study previously using Ordinary Method of Slice coding in MATLAB will be use to analyze slope stability by multiple iteration using Morgenstern – Price Method of Equation.

ACKNOWLEDGEMENT

To finish this Final Year Project, I would like to thank my supervisor, Assoc. Prof Dr. Indra Sati Hamonangan Harahap for his assistance and supervision throughout my journey to complete my project. Thank you for his patience and kind guidance in providing valuable knowledge in this field, thus has gave me a lot of new thing to be explore in the future.

Deepest appreciation to the lecturers of Civil & Environmental Engineering Department for theirs extensive supports and continuous encouragement for all the final year students.

Not only that, I would to express my gratitude to my family for giving me support throughout my journey in completion this project. Special appreciation to my friends who were there in helping me directly or indirectly in this venture.

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ABBREVATIONS & NOMENCLATURES

LEM	Limit Equilibrium Method
FEM	Finite Element Method
FOS	Factor of Safety

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Landslides are a common hazard that cause either caused naturally or due to activities by humans at the slope area. Landslide is also known as slope failure and can be analyze by slope stability analysis. There are several methods to analyze the slope stability but most common methods known are Limit Equilibrium Method (LEM) and Finite Element Method (FEM), (M. Duncan, 1996). The importance of analyzing slope stability is to ensure that the slope will not fail in a period of time when there are loading on the slope. When a slope fails, it will cause severe damage to the infrastructure or structure and also increasing the cost for restoring work. In Malaysia itself, there are various news reported on landslide incident. The most recent incident of landslide happened on last November 6, 2017 on a rainy day at Tanjung Bungah, Penang. According to an online newspaper, New Straits Time, written by Khairulrijal, (2017), the incident had caused a recently constructed row of luxury homes and also a double-lane road at the area to collapsed.

Limit Equilibrium Method has always been used in analyzing slope stability as it is the common method used by the research engineers and scientists, (Cheng, Lansivaara, & Wei, 2007). However, there are methods which does not satisfy all equilibrium forces, which are for example Ordinary or Fellenius Method and Bishop's Simplified Method. The only methods that fulfill the equilibrium forces are Morgenstern and Price Method, which are Interslice Force – Normal and Interslice Force – Shear, (Fredlund & Krahn, 1977).

In the field of the study, the Factor of Safety (FOS) of a slope is calculated by computing the equation using MATLAB. The results will be compared with other slope stability analysis by using LEM methods to satisfy the accuracy of computed FOS.

1.2 PROBLEM STATEMENT

A landslide is a form of mass wasting that includes a range of ground movement that could cause violent destructive events to the affected area. This events could cause loss of life, infrastructure and structure failures, and socioeconomic losses. Landslides occur due to many factors that trigger the movement and the mechanisms of the soil.

For many research, researches has shown studies that landslide occurrence can be monitored through various method such as zoning the potential area of landslide, analyses the slope stability. However, landslides magnitude varies. Therefore, when a rare and high-magnitude of landslide happened, the damages from this hazardous event is severe, and it will cost a lot to the country effected to repair or replace the damaged facility. As this type of event it is necessary to know the most efficient method to analyze the slope stability thus to be able to predict its impact to infrastructure.

1.3 OBJECTIVE

The objective of this research is to:

i. To calculate factor of safety by different type of slope stability analysis method on a circular slope failure.
ii. To study how a slope failure will effect on the failure mechanism of pipelines structures.

1.4 SCOPE OF STUDY

In this paper, the author will be focusing on several subjects which are:

- Limit Equilibrium Method to compute factor of safety of on a circular slope failure which are Fellenius or Ordinary Method (1936), Bishop's Simplified Method (1955) and Morgenstern & Price Method (1965).
- Failure mechanism of steel pipeline based on its alignment on a slope.

The scope of study also comprises of below items:

- Factors that triggers the occurrence of landslides with the types of landslides
- Slope failure modes
- Procedures to carry out slope stability analysis based on MATLAB

All significant finding are documented for further study.

CHAPTER 2

LITERATURE REVIEW

2.1 LANDSLIDE

According to Highland & Bobrowsky, (2008), the universal term to describe the downslope movement of soil, rock, and organic materials under the effects of gravity is classified as landslide . Landslide is another type of hazard that are caused by two factors which are Natural Causes and Human Causes, (Alexoudi, Manolopoulou, & Papaliangas, 2010). There are possibilities when these two factors are combined, it will causes a severe damages to the affected area of landslide.

There are several types of landslides according to Highland and Bobrowsky (2008). The classification of landslides are according to the type of movement and the type of materials contained. These basis features assist researches, geologists or any other professionals to specifically identify the types of landslide. Landslide materials are mainly comprises of rock and soil. On the other hand, to describe the internal mechanics of how landslide is displaced the type of movements' disclosure are fall, topple, slide, spread and flow.

Table 1 and Table 2 shows a list of factors triggering occurrence of landslide which are; a) Natural Causes and b) Human Causes. This list of elements are provided by Highland & Bobrowsky, (2008).

Table 1: Landslides due to Natural Causes taken from The Landslide Handbook: A Guide to Understanding Landslides

Natural Causes	
Geological Causes	Morphological Causes
• Weak materials	• Tectonic or volcanic uplift
• Susceptible materials	• Glacial rebound
• Weathered materials	• Glacial meltwater outburst
• Sheared Materials	• Fluvial erosion of slope toe
• Jointed or fissured materials	• Wave erosion of slope toe
• Adversely oriented mass discontinuity	• Erosion of lateral margins
• Adversely oriented structural discontinuity	• Subterranean erosion
• Contrast in permeability	• Vegetation removal
• Contrast in stiffness	

Table 2: Landslides due to Human Causes taken from The Landslide Handbook: A Guide to Understanding Landslides

Human Causes
• Excavation of slope or its toe
• Use of unstable earth fills, for construction
• Loading of slope or its crest
• Drawdown and filling (of reservoirs)
• Deforestation
• Irrigation and (or) lawn watering
• Mining/mine waste contamination
• Artificial vibration such as pile driving, explosions, or other strong ground vibrations
• Water leakage from utilities, such as water or sewer lines
• Diversion (planned or unplanned) of a river current or longshore current by construction of piers

The occurrence of specific type of landslide hazard may possibly due to one of the causes mentioned in the tables above. Epifânio, Zêzere, & Neves, (2014) conducted a research to achieve an array of landslides and its predisposing factors. Location of study is at the coastal cliff zone of Lourinhã located in Central Portugal. Based on their research, landslide predisposing factors that were identified from the cliff zone area are cliff evaluation, slope angle, potential solar radiation, slope curvature, lithological units and geological structure. From the findings obtained, Epifânio et al., (2014) revealed that each and every predisposing factors mentioned are both directly and indirectly associated to the incidence of landslide. Not only that, the same set of landslide predisposing factors possibly affected on different types of landslide to occur. These predisposing factors should be taken account to as it will lead to future instability of the area. Instability of slopes will lead to slope failure. In this case, gravitational and seepage forces are the root course to the instability in natural slopes, (J. M. Duncan & Wright, 2005).

2.2 SLOPE STABIITY ANALYSIS

Slope stability analysis is a crucial studies in assessing the stability of slope and also provide guidance in assessing their limitations, (Cheng & Lau, 2008). An article written by Urlainis, Shohet, and Levy (2015) discussing on extreme events with significant consequences. In the year 1999, an earthquake happened at Izmit, Turkey that causes failure of electric power supply, collapsing of few bridges and also interruption of the water supply system to the city.

Without a proper slope stability analysis, more severe slope failure could happen and definitely will effect and damage any properties, facilities or structure of the affected area of slope failure. The cost of restoration in other hand is extremely expensive. As stated by Alvarado-Franco et al., (2017), a record period between 1993 and 2012 given by the U.S. Department of Transportations Pipeline & Hazardous Materials Safety Administration (PHMSA) stated that property damages due to pipeline incidents specifically cost over more than 6.3 US$ billion. This number included the pipeline incident affected due to landslides.

Slope fails in four different modes, (Das & Khaled, 2013) which are Circular Failure or also known as Rotational Failure, Non-Circular Failure, Planar Slide and Wedge Failure. Slope failure modes are represented by the slope slip surface. Rotational slip explains on types of slope slip surface. Rotational slip consists of two failures which are circular failures and non-circular failures. Such site that experiences circular and non-circular failure are mine site, dump site or site that are heavily jointed with existence of fractured rock mass and very weak rock.

Circular failure is influenced by size and mechanical properties of the particles in the soil or the rock mass. While non-circular failure usually occurred at non-homogeneous soil condition. Planar slide or plane is a combinations of discontinuities in the rock mass form blocks or wedges within the rock which a free to move. Wedge failure on the other hand happened when the rock mass slides along two intersecting discontinuities which dip out of the cut slope at an oblique angle to the cut face.

It is an important act to understand the stability of a slope at it determines how the slope will fails, (Das & Khaled, 2013). Researcher in Japan, Hyodo, Orense, Noda, Furukawa, & Furui, (2012) studied on slope failures at a residential land on valley in Yamamoto, Japan. The purpose of the study is to get a grip on the mechanism of slope failures and also analyses slope stability. Factor of safety, is determined by dividing average shear strength of the soil, τ_f, with the average shear stress developed along potential failure surface, τ_d.

$$F_s = \frac{\tau_f}{\tau_d} \dots\dots\dots (1)$$

To determine Shear strength of soil, the soil parameters that should be taken into account are soil cohesion value, c', soil friction value, $\emptyset'$ and value of normal stress on the potential failure surface, σ'.

$$\tau_f = c' + \sigma' \tan \emptyset' \dots\dots\dots (2)$$

$$\tau_d = c'_d + \sigma' \tan \emptyset'_d \dots\dots\dots (3)$$

Therefore, Factor of Safety, F_s,

$$F_s = \frac{\tau_f}{\tau_d} = \frac{c' + \sigma' \tan \emptyset'}{c'_d + \sigma' \tan \emptyset'_d} \dots\dots\dots (4)$$

From the equation above,

Factor of safety with respect to cohesion, $F_{c'} = \frac{c'}{c'_d} \dots\dots\dots (5)$

Factor of safety with respect to friction, $F_{\emptyset'} = \frac{\sigma' \tan \emptyset'}{\sigma' \tan \emptyset'_d} \dots\dots\dots (6)$

Comparing equation (5) and (6), Factor of Safety, F_s can be written as,

$$F_s = F_{c'} = F_{\emptyset'}$$

If the value of F_s is equal to 1, then the slope is in a state of impending failure. Generally a value of 1.5 of the factor of safety is acceptable of a stable slope.

The most basic method in computing slope stability analysis is by using the fundamental formulation of two-dimensional (2D) slope stability method, (Cheng & Lau, 2008). To analyze slope stability, the methods that are commonly used is Limiting Equilibrium, (Craig, 2004). Ltd. (2012) publication has compiled various methods to compute the factors of safety which is based on limit equilibrium. Below are the list of limit equilibrium methods that has been compiled with a brief description on the slope stability analysis.

Factor of Safety Methods	
Name of Methods	**Description**
a. Ordinary or Fellenius Method (before 1936)	• First method of slice developed • Possible to compute factors of safety manually • Ignoring all interslice forces
b. Bishop's Simplified Method (1955)	• Method developed by Professor Bishop at Imperial College in 1950's • Included interslice normal forces, ignoring the interslice shear forces
c. Janbu's Simplified Method (1973)	• Similar to Bishop's method, however this method satisfies only overall horizontal force equilibrium
d. Spencer Method (1967)	• Developed by Spencer in 1967, developed two factor of safety equation • One with respect to moment equilibrium and another with respect to horizontal force equilibrium
e. Morgenstern-Price Method (1965)	• Developed similar to the Spencer method • Allowing user-specified interslice force functions: i. Constant ii. Half-sine iii. Clipped –sine iv. Trapezoidal v. Data-point specified
f. Corps of Engineers Method (1970)	• Characterized by specific interslice force function • Method only satisfies overall horizontal force equilibrium • Does not satisfies overall moment equilibrium • Has two assumptions about the interslice force: i. Uses the slope of a line from crest to toe ii. Uses the slope of the ground surface at the top of the slice
g. Lowe-Karafiath Method (1960)	• Essentially similar to Corps of Engineers method • Uses another variation on the assumed interslice force function; uses the average of the slope top and the base inclination • Considers both interslice shear and normal forces
h. Sarma Method (1975)	• Developed a stability analysis method for non-vertical slice or for general blocks
i. Janbu's Generalized Method (1973)	• Imposes a stress distribution on the potential sliding mass by defining a line of thrust

Table 3: Factor of Safety Method based on Limit Equilibrium Formulation – Taken from Stability Modeling with SLOPE/W Handbook.

To explain stability analysis, methods choosen to analyse is Method Of Slices, (Das & Khaled, 2013). Below are free body diagram and force polygon based on list of methods mentioned in Table 3.

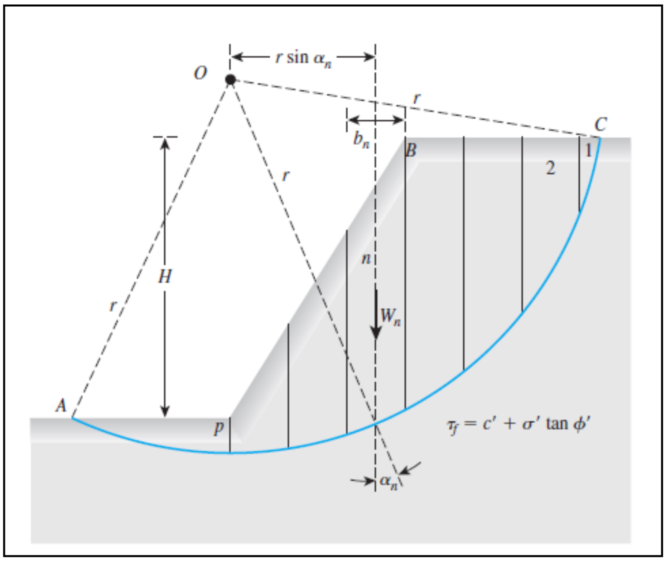


Figure 1: Stability Analysis by Method of Slices – Taken from Principles of Geotechnical Engineering (Das & Sobhan, 2014)

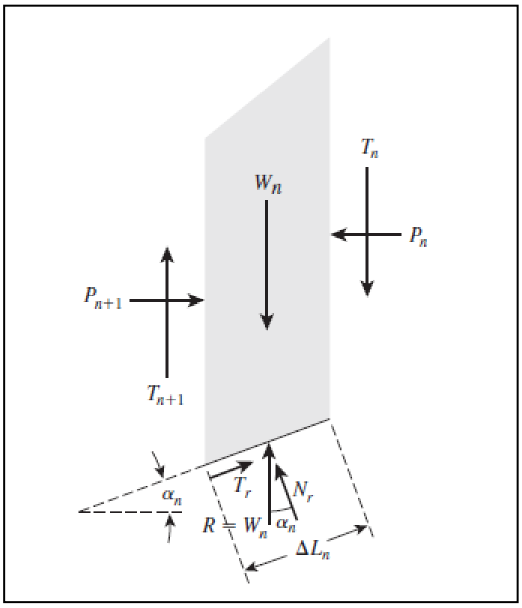


Figure 2: Forces acting on nth slice - Taken from Principles of Geotechnical Engineering (Das & Sobhan, 2014)

Figure 2 is a cross section taken from the trial failure surface of a slope. As the soil has been divided into several vertical slices width of each slices are not necessary to be at the same length.

Below are the description of the forces in each slices:

Forces	Description
Wn	Weight of the slices
Nr	Normal reaction force
Tr	Tangentional reaction force
Pn, Pn+1	Normal forces that act on the sides of the slice (Interslice force – Normal)
Tn, Tn+1	Shear force that act on the sides of the slice (Interslice force – Shear)

Table 4: Description Forces Acting On Slices

2.2.1 Ordinary Method of Slice

This method is the first method also referred as Swedish Method of Slices. As the method is the first developed, the simplicity of the method eases to understand the concept of method of slices. This method ignored all the interslice forces and consider equilibrium condition. Ordinary Method of Slice consists of individual forces which are Weight of the slices, W_n, Normal reaction force, N_r and Tangentional reaction force, T_r.

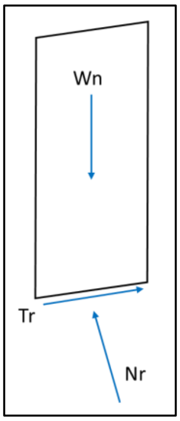


Figure 3: Force Polygon for the Ordinary Method

To that, to compute the factor of safety based on Ordinary Method of Slice, the equation is written as follows:

$$FS = \frac{\varepsilon\,(c\,\Delta\,L_n + \;W_n \cos\alpha_n\;\tan\emptyset\,)}{\varepsilon\,W_n\;\sin\alpha_n}$$

Equation 1: Factor of Safety for Ordinary Method of Slice

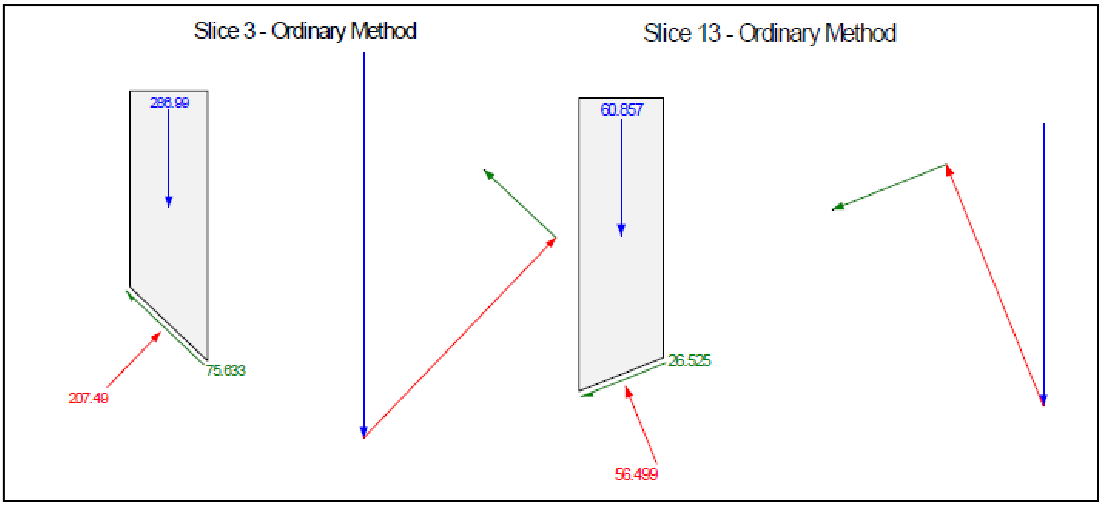


Figure 4: Free body diagram and force polygon for the Ordinary method – Taken from Stability Modeling with SLOPE/W by GEO-SLOPE International Ltd. (Ltd., 2012)

2.2.2 Bishop's Simplified Method

Bishop's Simplified Method was introduced by Professor Bishop at Imperial College London. This method compared to Ordinary Method, included interslice normal force, but ignored the interslice shear forces. The forces consists at the slice of the soil are Weight of the slices, W_n, Normal reaction force, N_r, Tangentional reaction force, T_r and Normal forces that act on the sides of the slice (Interslice forces – Normal), P_{n+1}.

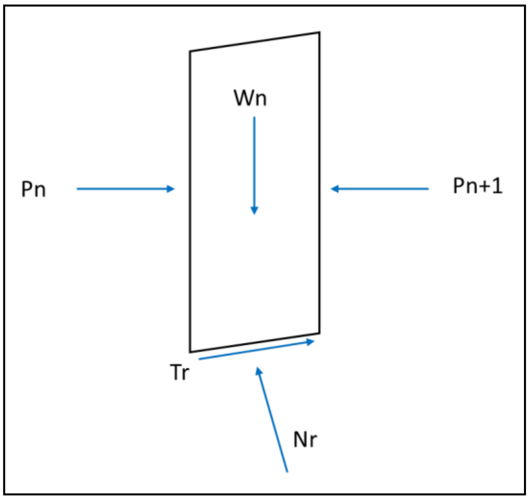


Figure 5: n-th Slice with forces acting based on Bishop's Simplified Method

To compute the factor of safety based on Bishop's Simplified Method, the equation is written as follows:

$$FS = \frac{\varepsilon\,(\,c'b_n + \,W_n\,\tan\emptyset'\,)}{\varepsilon\,W_n\sin\alpha_n\ m_{\alpha(n)}}$$

Equation 2: Factor of Safety for Bishop's Simplified Method

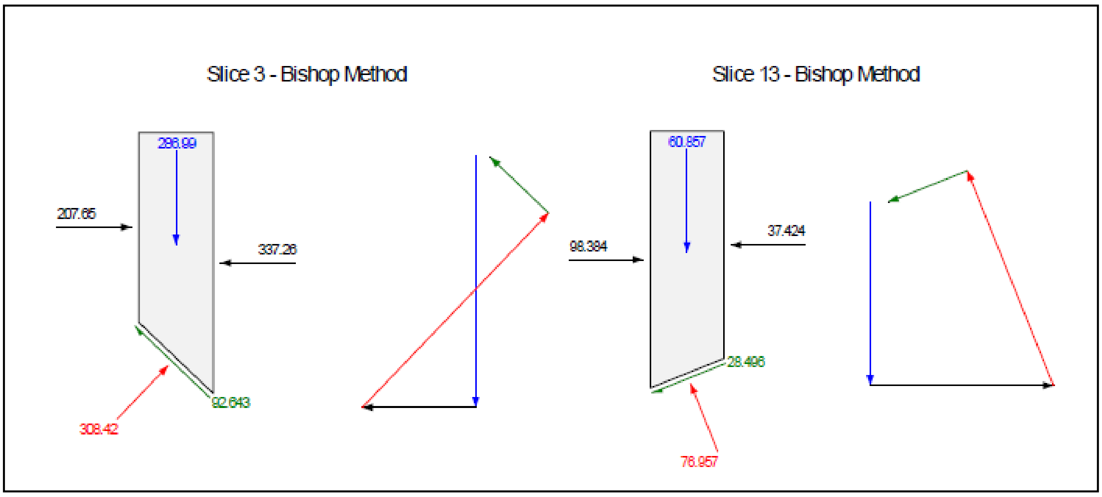


Figure 6:Free body diagram and force polygon for the Bishop's Simplified method – Taken from Stability Modeling with SLOPE/W by GEO-SLOPE International Ltd. (Ltd., 2012)

2.2.3 Morgenstern-Price Method

Morgenstern-Price (1965) developed a method allowing all interslice force functions. This method satisfy equilibrium of forces and moments acting on individual slices. Forces acting on the slice are Weight of the slices, W_n, Normal reaction force, N_r, Tangentional reaction force, T_r, Normal forces that act on the sides of the slice (Interslice forces – Normal), P_{n+1} and Shear forces that act on the sides of the slice (Interslice force – Shear), T_{n+1}. Each slice is assumed to contribute due to the same forces as Spencer Method, (Fredlund, Krahn, & Pufhal, 1981).

Following are the assumptions in Morgenstern-Price Method:

- Slices dividing are always vertical
- The line of action of weight of block, W_n passes through the center of the n^{th} segment of slip surface represents by point M
- The Normal force, N_r is acting in the center of the n^{th} segment of slip surface, at point M
- Inclination forces E_n acting between slices is different on each slice (δ_n) at slip surface end points is $\delta = \ 0$

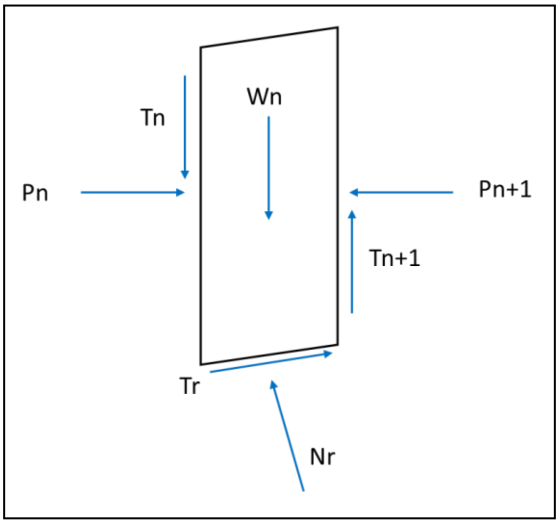


Figure 7: Factor of Safety for Morgenstern - Price Method

The equation to compute Factor of Safety based on Morgenstern- Price Method is likely different from previous two methods. According to, Fredlund, Krahn, & Pufhal, (1981) mentioned that Morgenstern-Price (1965) uses summation of forces tangential and normal force to the base of a slice and also summation of moments about center of the base of each slice. The combination of both equation, modification by Newton-Raphson numerical technique was applied. The solution of factor of safety were then solved by using functional form which is as below equation:

$$X/E = \lambda f(x)$$

Equation 3: Function Equation for Morgenstern-Price Method

Forces	Description
X	Vertical interslice shear forces
E	Horizontal interslice normal forces
$\boldsymbol{\lambda}$	A constant representing the percentage
$\boldsymbol{f(x)}$	A function that describe the manner in which X/E varies across the slope

Table 5: Description on Function Equation for Morgenstern-Price Method

Above equation are used in most developed computed software. According to Fredlund et al., (1981), the long equation of force and moment equilibrium of Morgenstern – Price Method were combined and modified to suits in analyzing slope of circular or non-circular condition.

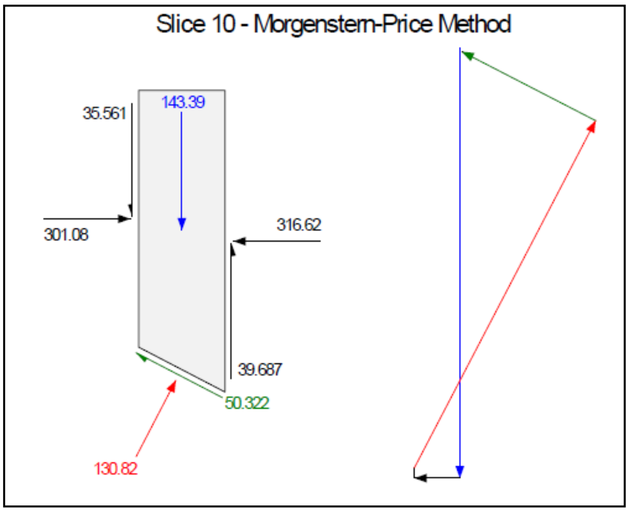


Figure 8: Free body and force polygon for Morgenstern-Price method – Taken from Stability Modeling with SLOPE/W by GEO-SLOPE International Ltd. (Ltd., 2012).

2.3 PIPELINE FAILURE DUE TO SLOPE FAILURE

Various studies have been conducted in regard to pipeline failure located at a slope. Liu et al., (2017) studied on buckling failure mode analysis on buried X80 steel gas pipelines. Due to reverse fault displacement, the pipeline underneath it has failed. Liu et al., (2017) uses numerical analysis to develop finite element modelling, compute algorithms for nonlinear buckling analysis and validate the modelling. Buckling failure is highly nonlinear for high strength pipeline. In the modelling, both buckling failure: both beam and local occurred relatively dependent to the dip angle and also the thickness of the pipeline. According to Liu et al., (2017), both beam and local buckling failure will occur when dip angle, $\varphi < 75°$, and only local buckling failure when dip angle is $\varphi \geq 75°$. As for the thickness of the pipe wall, $t < 22$ mm would result to local buckling failure first then followed by beam buckling failure.

Melissianos, Korakitis, Gantes, & Bouckovalas, (2016), have also conducted a numerical research which related to flexible joints (hinged bellow-type) in buried pipelines which subjected to strike-slip fault rupture. Due to developing of longitudinal tensile, compressive strains and highly risk failure of pipeline, the researches focuses on the effectiveness of the flexible joints. According to Melissianos et al., (2016), the geological conditions and soil properties at the fault crossing site may introduced to uncertainty regards to the fault trace location. (Melissianos et al., 2016) suggested the appropriate type of flexible joint to be choose is metallic hinged elbow-type and due to uncertainty of fault location, it is best to integrate joints along the entire pipeline length.

Podimata, (2016), studied on the impact of gas pipeline due to a large earthquake. Her work focuses on developing a methodological attempt to assess the environmental impacts of the gas pipeline due to failure after a strong earthquake. From the study, it has found that intersection between pipelines with active faults will trigger severe damages in environment. Therefore, it is essential for primary environmental study to identify possible earthquake approaches in order to mitigate risk during three different periods; construction, operation and shutdown phases of pipeline project.

Zhao & Song, (2016), carried out a study related natural gas pipeline failure analysis. Results of the study shows that due to stress concentration, axial mechanical scratches were identified thus reduces the pipeline effective bearing thickness. This scenario triggers the stress corrosion cracks which will then lead to the blast of natural gas pipeline.

Corresponding to that, Einsfeld, Murray, & Yoosef-Ghodsi, (2003) conducted a numerical study related to local buckling using finite element commercial package (ABAQUS) on high temperature pressurized pipelines. The purpose of the study is to provide a tool to evaluate the susceptibility to buckling for different load conditions on the pipe. With that, a proper mitigation action can be engaged due to thermal buckling.

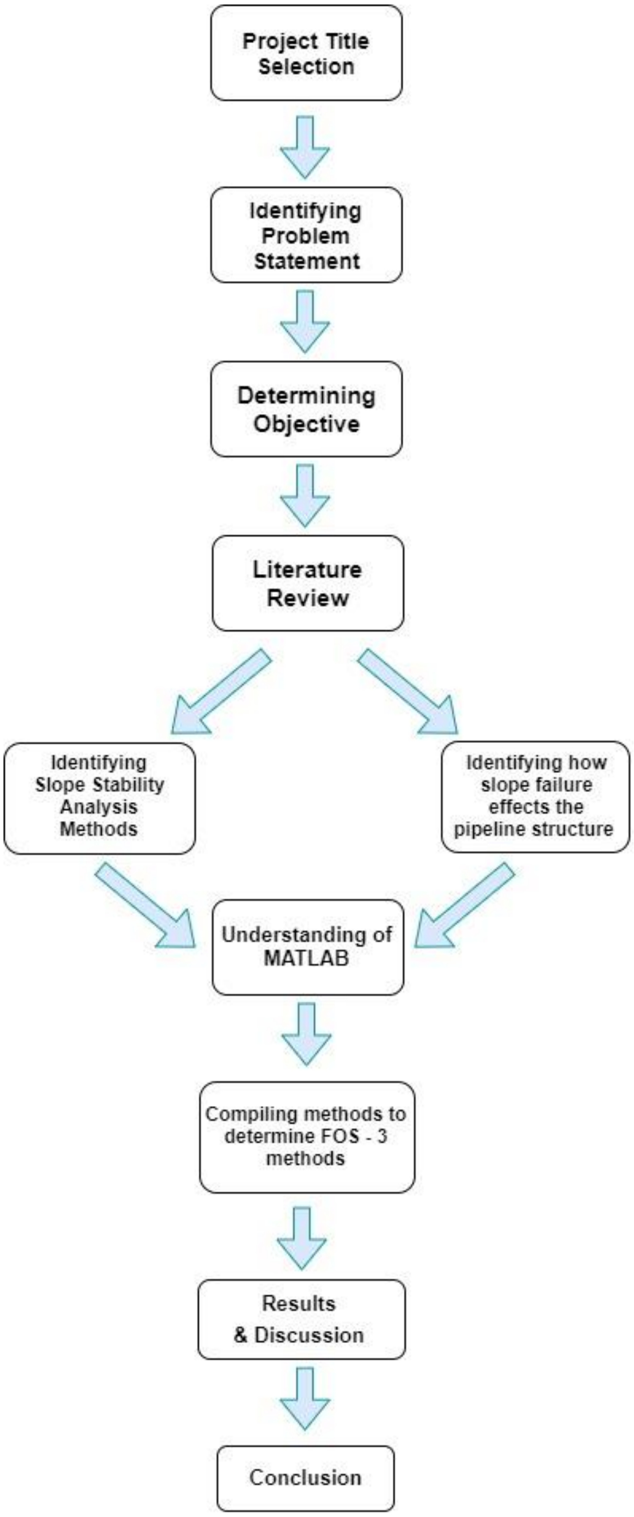
Girgin & Krausmann, (2014) mentioned that with continuation of analyzing incident data, it may help to identifying the impact and failure modes for future accident prevention. Not only that, mitigation plan may also be able to draft based on the consequences of the failure. In their study, they had emphasize on the importance of using a structured database to study the impact of natural events in detailed.

Mahmoodian & Li, (2017) conducted an analytical study on the failure assessment of oil and gas pipelines. According to Mahmoodian & Li, (2017), the factor influencing the failure of pipelines is due to its corrosion rates.

CHAPTER 3

METHODOLOGY

3.1 FLOWCHART



3.2 RESEARCH METHODOLOGY

In completion of this research study, a parametric study is used to check the validity of the results from the MATLAB coding to achieve the first objective. Slope stability equations will be coded in MATLAB to calculate Factor of Safety of a slope. The coding will be based on Morgenstern and Price Method.

As for the second objective for this research study, to identify pipeline failure mechanism, a theoretical study has been chosen. From this theoretical study, various articles and journal paper are used to understand the pipeline failure mechanism effected by a slope failure.

3.3 SLOPE STABILITY ANALYSIS

Morgenstern – Price Equation

Morgenstern –Price method was chosen in completion of this research study. Below are the equations that will be included in the coding of MATLAB software to identify the factor of safety.

$$X/E = \lambda\, f(x)$$

Equation 4: Function Equation for Morgenstern-Price Method

Forces	Description
X	Vertical interslice shear forces
E	Horizontal interslice normal forces
$\boldsymbol{\lambda}$	A constant representing the percentage
$\boldsymbol{f(x)}$	A function that describe the manner in which X/E varies across the slope

Other software that are used to analyses slope stability are using the equation above. By several iteration, the λ is the constant in identifying the variation of factor of safety. However in this research, Equation 5, 6 and 7 will be used in order to compute the factor of safety. The method to solve is similar to Spencer's method which is also by iteration.

$$N'_i + U_i - W_i.\cos\alpha_i + K_h.W_i.\sin\alpha_i + Fy_i.\cos\alpha_i - Fx_i.\sin\alpha_i + E_{i+1}.\sin(\alpha_i - \delta_{i+1}) - E_i.\sin(\alpha_i - \delta_i) = 0$$

Equation 5: Force Equation of Equilibrium in the Direction Normal To The ith Segment of the Slip Surface.

$$N'_i.\frac{\tan\varphi_i}{FS} + \frac{c_i}{FS}.\frac{b_i}{\cos\alpha_i} - W_i.\sin\alpha_i - K_h.W_i.\cos\alpha_i + Fy_i.\sin\alpha_i + Fx_i.\cos\alpha_i - E_{i+1}.\cos(\alpha_i - \delta_{i+1}) + E_i.\cos(\alpha_i - \delta_i) = 0$$

Equation 6: Force Equation of Equilibrium along the ith Segment of the Slip Surface.

$$E_{i+1}.\cos\delta_{i+1}\left(z_{i+1}-\frac{b_i}{2}\tan\alpha_i\right)-E_{i+1}\sin\delta_{i+1}.\frac{b_i}{2}$$
$$-E_i.\cos\delta_i\left(z_i-\frac{b_i}{2}\tan\alpha_i\right)M1_i-K_h.W_i\left(y_m-y_{gi}\right)=0$$

Equation 7: Moment Equation of Equilibrium about Point M

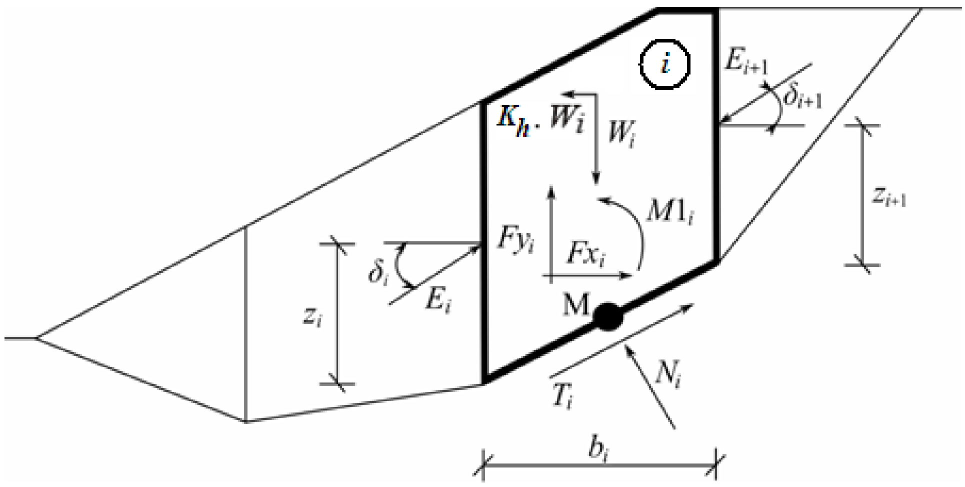


Figure 9: Static scheme of Morgenstern - Price Method for ith slice

Based on the schematic scheme of the ith slice according to Morgenstern-Price Method, below are the explanation of the forces in each of the equations above:

W_i	block weight, including material surcharge having the character of weight including the influence of the coefficient of vertical earthquake K_v
K_h*W_i	horizontal inertia force representing the effect of earthquake, K_h is the factor of horizontal acceleration during earthquake
N_i	normal force on the slip surface
T_i	shear force on the slip surface
E_i ,E_{i+1}	forces exerted by neighboring blocks, they are inclined from horizontal plane by angle δ
Fx_i,Fy_i	other horizontal and vertical forces acting on block
$M1_i$	moment of forces Fx_i, Fy_i rotating about point M, which is the center of the ith segment of slip surface
U_i	pore pressure resultant on the ith segment of slip surface

Both horizontal and vertical factor coefficient of earthquake will be ignored in this study. This is because the slope to be study assumed to be free from the occurrence of earthquake.

MATLAB Coding

A MATLAB coding will be constructed based on equations on slope stability analysis. The coding will apply Morgenstern-Price Method and will compute Factor of Safety along a slope by using method of slices. The types of slope in this study is not specified. Few functions in the MATLAB of previously is an Ordinary Method function will be modified accordingly to Morgenstern – Price Method. Few forces will be neglected such as the earthquake coefficient. However, this coefficient can be included in the future studies.

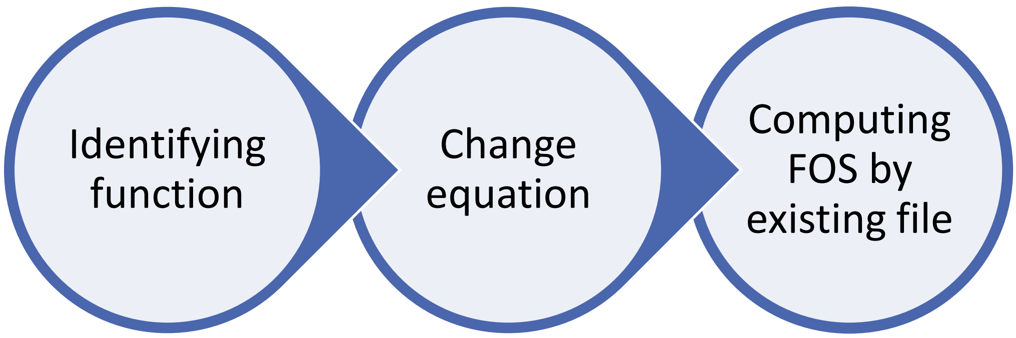
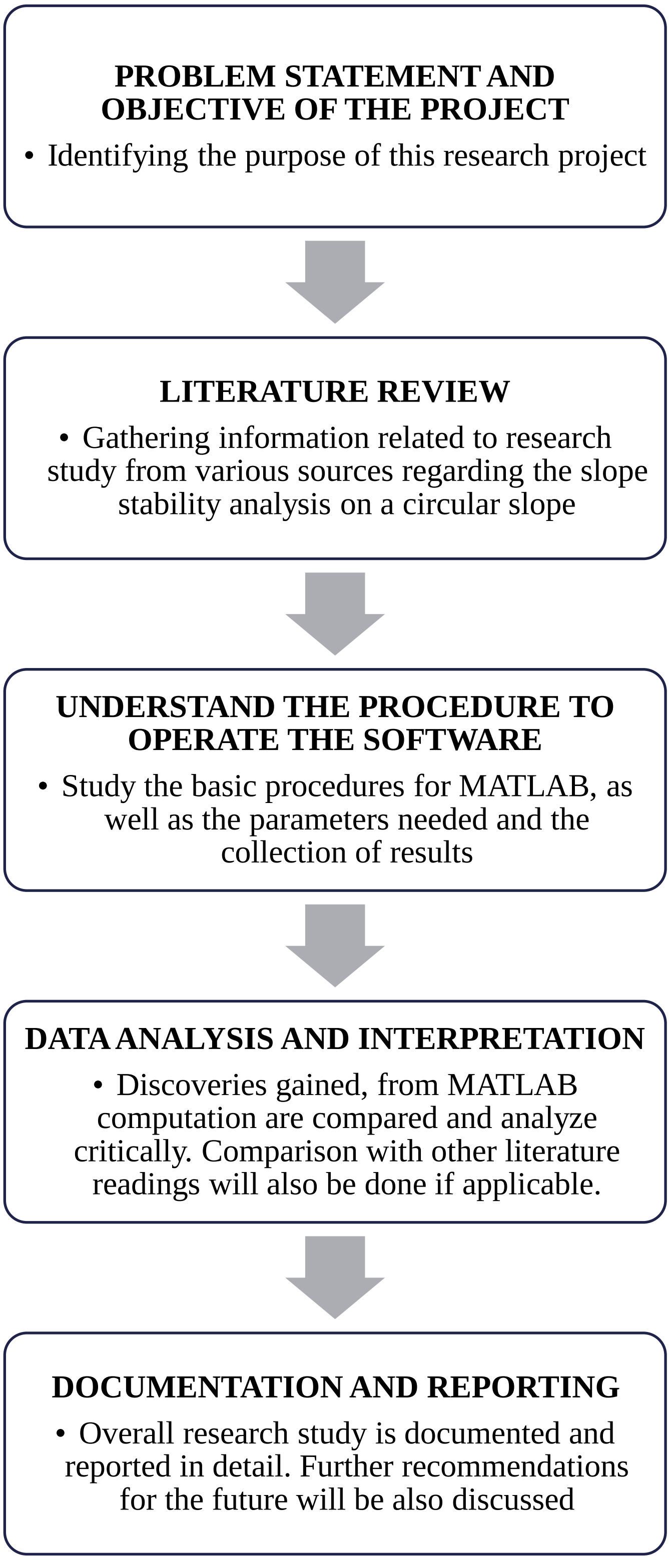


Figure 10: Flow diagram to compute factor of safety by using MATLAB

3.4 INFRASTRUCTURE FAILURE

A theoretical study on infrastructure failure mainly pipeline use for oil and gas industry. Various article paper and also real life incident that occurred will be used to understand how the alignment of pipes on a slope will be effected when landslide occurred. In this research, the only focus will be on the alignment of pipes on the slope. Other considerations such as the dimensions, properties of pipe will not take into account in this study.

3.5 KEY MILESTONES



3.6 GANTT CHART OF PLANNING ACTIVITIES ON FYP 1

No.	Activities	Week No													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Selection of project title														
2.	Preliminary research work														
3.	Identifying Problem Statement and Objective														
4.	Literature Review														
5.	Submission of First Draft														
6.	Submission of Extended Proposal														
7.	Identifying LEM to compute FOS for Slope Stability Analysis														
8.	Proposal Defense Presentation														
9.	Detailed Literature Review														
10.	Project Work Continues														
11.	Submission of interim report														

3.7 GANTT CHART OF PLANNING ACTIVITIES ON FYP 2

No.	Activities	Week No													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Literature Review														
2.	Data and Parameters Collection														
3.	Familiarizing with MATLAB														
4.	MATLAB Computation for Slope Stability														
5.	Analysis of Results														
6.	Submission of Progress Report														
7.	Pre - SEDEX														
8.	Submission of Final Draft Report														
9.	Submission of Dissertation and Technical Paper														
10.	Viva Presentation														

CHAPTER 4

RESULTS & DISCUSSION

4.1 FACTOR OF SAFETY

Based on literature research, Morgenstern-Price Method are more competent in providing better value of factor of safety compared to Ordinary Method. To satisfy the statement mentioned, a program by using of Morgenstern-Price method is constructed with by including the equations in the function. The derivation of Morgenstern-Price Method is more consistent compared to other method of slices, (Fredlund & Krahn, 1977).

However, due to certain circumstances and lack of time the factor of safety for the slope are Morgenstern-Price Method is could not be satisfied.

4.2 PIPELINE FAILURE

Based on theoretical research, steel pipe could be subjected to compression force or tensile force. Two alignment of pipeline has been chosen for this study. Figure 10 is the first position of the pipe on a slope which is perpendicular to the direction of the slope, and Figure 11 shows a pipe alignment parallel to the slope.

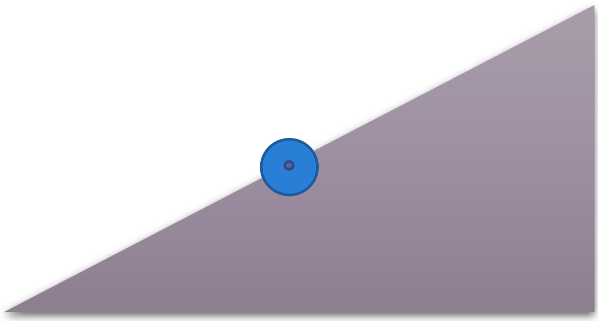


Figure 11: Perpendicular alignment of pipe on a slope

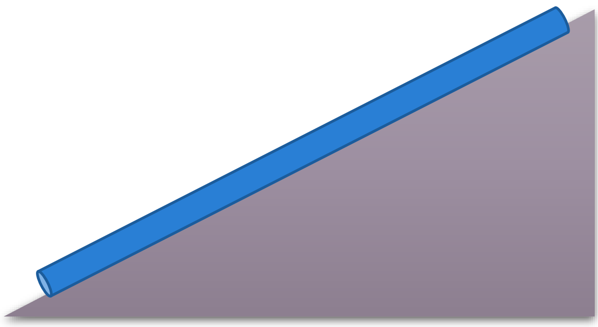


Figure 12: Parallel of pipe alignment on a slope.

As the pipe were subjected to compression the most likely condition that could happen to the pipe is buckling, and for pipe subjected to tensile force most likely will fracture. From the figures above, as the pipe were aligned perpendicular to the direction of the slope, when landslide occur, the soil mass movement could cause compression and tension to the pipe, thus the pipe could either encounter local buckling or beam buckling or shear failure. However, further modeling by using appropriate software can be used to check on how landslide could effect on the pipeline failure mechanism.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

In conclusion, the principle of using Factor of Safety is its advantage of the method which is the simplicity and lucidity of the method. By using Morgenstern-Price Method equation with the aid of MATLAB software is important as the method take into consideration all forces acting on the slope. MATLAB software is used as its ability to interpret language which is dynamic and inferenced types. This software has high-level language ability with a good syntax to perform operations such as matrices. Therefore, by using MATLAB, more reliable results can be depended on.

For further researches on this related field, there are few recommendations that can be done in the future. In the further research, to model a pipeline as a surcharge on a slope to be considered when analyzing the slopes stability. Besides that, considering different soil parameters can be included in the future parametric variation study. Combining these two scope of study, further risk assessment and analysis can be made in order to control the damaged caused by slope failure.

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