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Stability Analysis of Reclamation Area Embankment Slope in West Java Port by Simplified Bishop Method

Cokorda Bagus Purnama Dwisa[a], Ali Sumara El Khomeiny[b] , Fendy Triandy[c]
[a,b,c] Institut Transportasi dan Logistik Trisakti, Jakarta, Indonesia
Corresponding author: cokorda.bagus@gmail.com

Abstract: A port in West Java plans to construct reclamation area to expand the land area of service. The construction of terminal expansion is programmed in several stages. Hence, the reclamation area will have slope during the project until the whole of the work is completed. Slope stability analysis is performed to ensure the stability of the slope by using Simplified Bishop Method. The soil parameter to determine the shear strength of the soil was taken from the project soil investigation. The safety factor criteria is set to be 1.25 as the limit of slope failure. The result shows that the safety factor from three Bishop slice trials are consecutively 1.63, 1.50 and 1.30. Thus, the slope of reclamation area is considered to be safe.
Keywords: *Reclamation, Slope Stability, Shear Strength, Safety Factors, Bishop Method*

1. Introduction

A port in West Java is currently expanding the port area through reclamation of a number of water areas. There are several large parts of the reclamation area development, namely the stock yard area on the West side with an area of approximately 5000 square meters, the stock yard area on the East side with the same area of approximately 5000 square meters and the future stock yard which will be built in the next phase. The port management also plans to build a 230-meter quaywall with a width of 14 meters as a boundary between the sea side and the stock yard area. Detailed drawings of the reclamation area development plan are shown in Figure 1.

The project will be executed in several phase for several years. The stock yard phase 2A work plan will be carried out first so that there is an empty area on the South side bordering the future reclamation area. This will result in embankments with slopes on the South side until the phase 2B reclamation process is carried out. The main thing that needs to be considered in this situation is the planning of embankments and slope stability formed on the border of phase 2A and phase 2B. This is because it concerns human safety (workers), equipment safety, and smooth production related to the timeline of project completion and safety in the operational phase. For this reason, a slope stability analysis needs to be carried out. One of the objectives of slope stability analysis is to evaluate slope stability, either artificial or natural slopes, evaluate the possibility of slope failure, and plan redesign and preventive measures for slopes that have collapsed. The shear strength value of the soil along the slip plane has to be greater than the load received by the slope along the slip plane indicating that the slope is stable or not collapsing.

Various methods can be used to conduct slope stability analysis. One of the most commonly

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used is the slice method or the Bishop method. Bishop method, introduced by A.W. Bishop, uses a slice approach where the forces acting on each slice are analyzed. This method is used to analyze a circular slip surface. In Bishop method, it is assumed that the total normal forces act at the center of the base of the slice and can be calculated by decomposing the forces vertically or normally on each slice. Equilibrium requirements are applied to each slice that forms the slope. This method also assumes that the resultant forces acting on the slice are zero in the vertical direction (Bishop, 1955).

This study will calculate the slope stability analysis using Simplified Bishop Method modeling to predict slope behavior in the reclamation area in the Phase 2A Terminal Development project before Phase 2B Work begins.

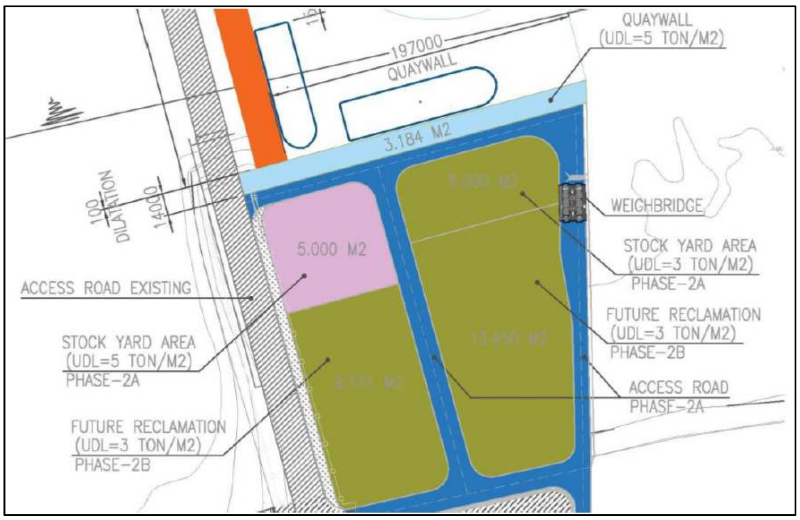

Fig. 1. Reclamation Area Development Plan
Source: Project Data (2024)

2. Literature review

Slope failure is the movement of rock soil mass in a vertical, horizontal, or sloping direction from its original position because of the slope's inability to withstand the shear force acting on the boundary between the moving mass and the stable mass. Terzaghi (1950) divides the causes of slope failure into two main causes namely internal influences and external influences. Landslides that occur due to internal influences involve factors that cause decreased strength, including water absorption, increased pore water pressure, shock loads or repeated loads, the effect of freezing and thawing, loss of material cementation, weathering processes and excessive strain on sensitive clay. Whereas slope failure due to external influence occur because of factors that cause increased stress, namely increased soil unit weight due to wetting, additional external loads, increased slope steepness due to natural erosion or excavation and the

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action of shock loads.

In general, slope stability analysis methods can be divided into visual observation method, computational method, and graphical method (Astuti, 2016).

1. Visual observation method is a method of direct observation in the field by comparing the conditions of the slope that is moving or estimated to move and those that are not. This method estimates unstable or stable slopes by utilizing experience in the field, hence this method is less accurate, depending on the person's experience (Pangular, 1985 in Feriyansyah, 2013). This method is used if there is no risk of landslides occurring during observation.
2. Computational method is a method of calculation based on the formula developed by previous researchers e.g., Fellenius, Bishop, Janbu, Sarma. Those formula are widely used in geotechnic field. Many computational programs have also been modelled and programmed by applying one or more of those theories and formulas.
3. Graphical method is using a standard graph developed by previous researchers e.g., Taylor, Hoek & Bray, Janbu, Cousins and Morganstren. Graphical methods are more simplified than computational method. Hence, these graphs have certain limitation of application.

Slope stability analysis is based on the concept of plastic limit equilibrium. Hardiyatmo (2023) summarized several assumptions to perform slope stability analysis, which are:

1. Slope landslides occur along the surface of a particular landslide plane and can be considered as a 2-dimensional plane problem.
2. The landslide mass is considered a massive object.
3. The shear resistance of the soil mass at each point along the landslide plane does not depend on the orientation of the landslide surface, or in other words the soil shear strength is considered isotropic.
4. The safety factor is defined by considering the average shear stress along the potential landslide plane, and the average soil shear strength along the landslide surface.

Based on the assumption that the slip surface is in the form of a circular curve, the force pushing the soil mass above the curve must be compared with the shear force resisting the landslide along the curve. The thrust and resistance forces depend on the position and radius of the curve, so the analysis must be carried out with various assumptions. Thus, the safety factor (SF) can be calculated as the ratio between the forces causing the slide and the forces resisting the slide. The safety factor (SF) must be more than 1.0 to ensure slope stability because the slope is almost in critical condition and at risk of landslides. Bowles J.E. (1989) explains that slope conditions based on the safety factor (SF) value can be seen in Table 1.

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Table 1
Slope Safety Factor

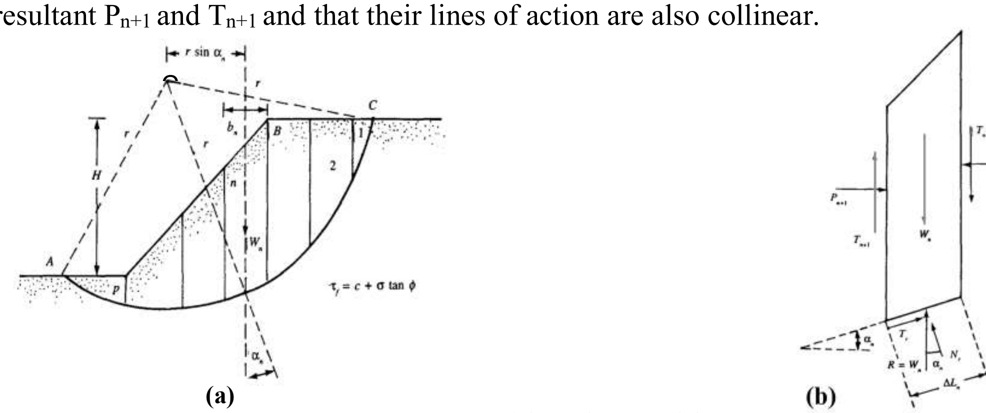
Safety Factor (SF)	Slope Condition	Landslide Intensity
SF<1,07	Instable	High Possibility
1,07>SF<1,25	Critical	Medium Possibility
1,25>SF	Stable	Less Possibility

Source : Bowles (1989)

Bishop's simplified method (Bishop, 1955) assumes that the forces acting on the sides of the slice have a zero resultant in the vertical direction. The Bishop method is used to analyze slip surfaces that are circular. In this method there are several assumptions, including:

1. The failure is assumed to be due to the rotational movement of the soil in which the collapse is circular. This method cannot be used to calculate the safety factor of a collapse that does not have a circular collapse plane.
2. The value of the horizontal force on both sides can be ignored because its value is unknown and difficult to calculate.
3. The normal force acting is assumed to work in the middle of the slice plane and is obtained by summing up the forces in the vertical direction.

Bishop slice method divides the landslide mass into several vertical slices. The width of each section may vary. Figure 2(a) shows an embankment with AC being a circular curve as the experimental landslide surface, while Figure 2(b) shows a unit thickness perpendicular to the cross section of the embankment as shown with the forces acting on a particular section. W_n is the section weight; while the forces N, and T, are the vertical and parallel components of the reaction R. P_n and P_{n+1} are the normal forces acting on the sides of the section. Similarly, the shear forces acting on the sides of the section are T_n and T_{n+1}. For simplicity, the pore water pressure is assumed to be zero. The forces P_n, P_{n+1}, T_n, and T_{n+1} are difficult to determine. However, we can make an approximate assumption that the resultant P_n and T_n are equal to the resultant P_{n+1} and T_{n+1} and that their lines of action are also collinear.



(a) (b)

Fig. 2. Bishop Slope Model
Source: Das (1985)

For the equilibrium of the experimental block ABC, the resultant of moments acting on point O should be equal to zero. Bishop Slope Model derives the equation of Safety Factor as follow:

$$Fs = \frac{\sum_{n=1}^{n=p}(c\,\Delta L_n + W_n \cos\alpha_n \tan\phi)}{\sum_{n=1}^{n=p} W_n\, r\, \sin\alpha_n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where: $\Delta L_n = \frac{b_n}{\cos\alpha_n}$

Simplification of Bishop Method was then introduced as a more accurate solution than the simple method of sections. In this method, the effects of forces on the edges of each section are taken into account. Figure 2(b) shows the forces acting on section number n. Based on Simplified Bishop Method, it is derived that: $P_n - P_{n+1} = \Delta P$ and $T_n - T_{n+1} = \Delta T$. The Factor of safety based on Simplified Bishop Model is determined as follow:

$$Fs = \frac{\sum_{n=1}^{n=p}(cb_n + W_n \tan\phi)\frac{1}{m_{\alpha_n}}}{\sum_{n=1}^{n=p} W_n \sin\alpha_n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where: $m_{\alpha_n} = \cos\alpha_n + \frac{\tan\phi \cdot \sin\alpha_n}{Fs}$

3. Research method

This study is performed in a port in West Java area. Detail of port's plot plan is shown in Figure 1, while the slope of reclamation area in the Phase 2A Terminal Development project is modelled as shown in Figure 3.

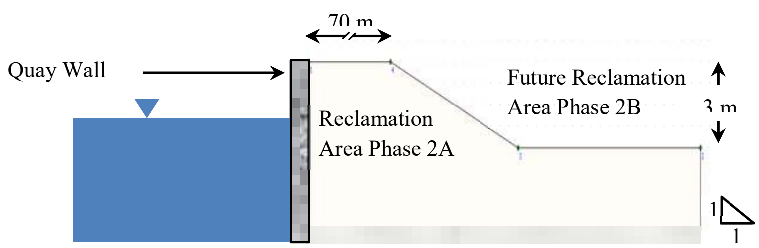


Fig. 3. Reclamation Slope Model
Source: Project Data (2024)

The research step starts with soil data acquisition, i.e., physical properties which are soil unit weight and elastic modulus, cohesion, and friction angle. Working load on Reclamation Area

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Phase 2A has been defined based on Project Data. The next step is defining the slope assumption to be analyzed by using Simplified Bishop Method. The study is completed when three slope assumptions have been calculated to have Factor of Safety more than 1,25. Figure 4 shows the flow chart of this study.

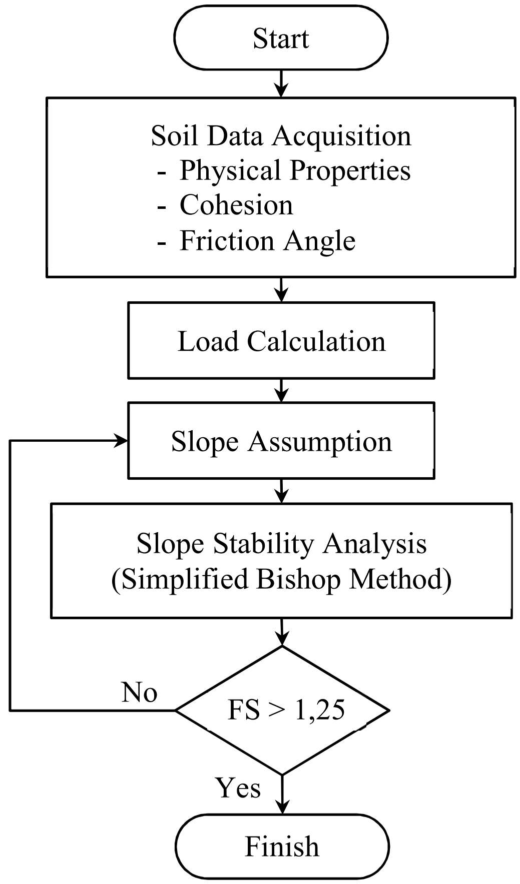

Fig. 4. Flow Chart

Soil properties data is obtained by taking soil sample in the location of Reclamation Area Phase 2A. The soil sample is tested in the laboratory to obtain its physical properties. Further triaxial test is performed to obtain the value of cohesion and friction angle. These parameters are used to exercise the shear resistance of the soil embankment to be compared to the 5 Ton/m^2 working load.

Slope Stability Analysis is performed by using Simplified Bishop Method with the steps as follow and the illustration shown in Figure 5:

1. Define the scale of the drawing and draw the embankment based on the drawing scale.
2. Define the center of the collapse plane (namely 'O') and draw the assumed collapse

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plane.

3. Divide the soil mass above the collapse plane into several parts and define the mass center of each part.
4. Draw auxiliary lines from O to the intersection of mass center line and the collapse plane.
5. Define the value of α (angle between auxiliary lines and mass center line).
6. Calculate the area of each soil mass part, namely An.
7. Calculate the weight of each soil mass part, namely Wn.
8. Calculate FS by using Formula (2).

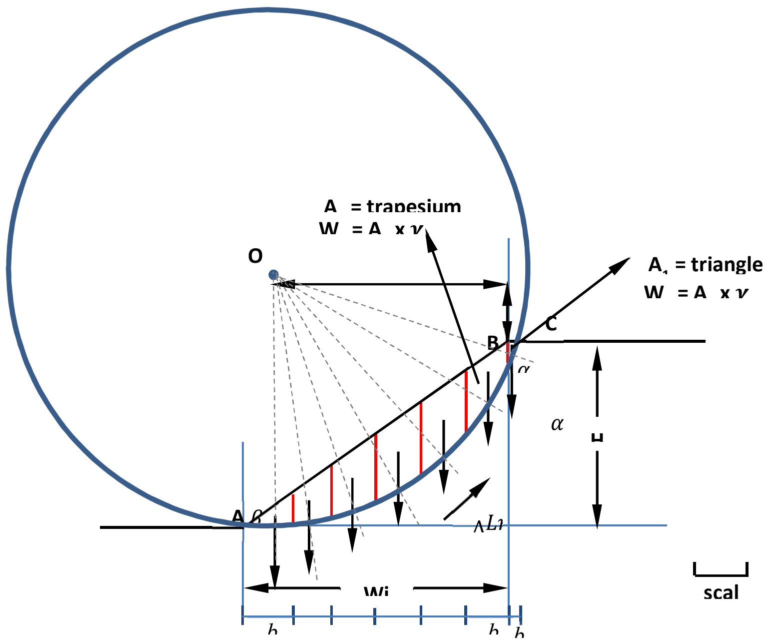

Fig. 5. Simplified Bishop Method Illustration

Formula (2) has Fs variable in both sides of the equation. Therefore, a trial calculation method is carried out to determine the value of Fs. Das (1985) developed a tabulation method as an empiric trial to calculate the Fs value. Table 3 shows the illustration of the empirical method by Das (1985).

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Table 2
Fs Calculation Illustration

Slice No. (1)	W_n (kN/m) (2)	α_n (deg) (3)	$\sin \alpha_n$ (4)	$\cos \alpha_n$ (5)	ΔL_n (m) (6)	Wn . sin α_n (kN/m) (7)	Wn . cos α_n (kN/m) (8)
1							
.							
.							
.							
n							
					$\sum col\ (6)$	$\sum col\ (7)$	$\sum col\ (8)$

Source : Das (1985)

The Formula (2) is modified as the following Formula (3) to determine the value of Fs based on the tabulation value in Table 2.

$$Fs = \frac{(\sum col\ (6))(c) + (\sum col\ (8))(\tan \phi)}{\sum col\ (7)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

4. Results and discussion

Table 3 shows the soil data properties derived from soil sampling and laboratory test. These parameters are used to determine the soil shear strength against the design load 5 ton/m2.

Table 3
Soil Properties

Cohesion	Friction Angle	Unit Weight
5 kN/m^2	25^o	16 kN/m^3

Source : Bowles (1989)

Based on the illustration in Figure 3, soil embankment and its slope failure assumption are drawn in scale as shown in Figure 6. The drawing was created by following the steps based on slope stability analysis using Simplified Bishop Method.

The calculation step for slice no.1 of the failure mass is given below.

Data:
c = 5 kN/m^2
ϕ = 25°
γ = 16 kN/m^3
α_1 = 74°
Sin α_1 = 0,96
Cos α_1 = 0,28
b_1 = 0,3 m
Calculation:
A_1 = 0,13 m^2

$W_1 = 0{,}13\ m^2 \times 16\ kN/m^3 = 2{,}08\ kN/m$
$\tan \phi = 0{,}46$
$W_1 . \sin \alpha_1 = 2{,}00\ kN/m$
$W_1 . \cos \alpha_1 = 0{,}57\ kN/m$

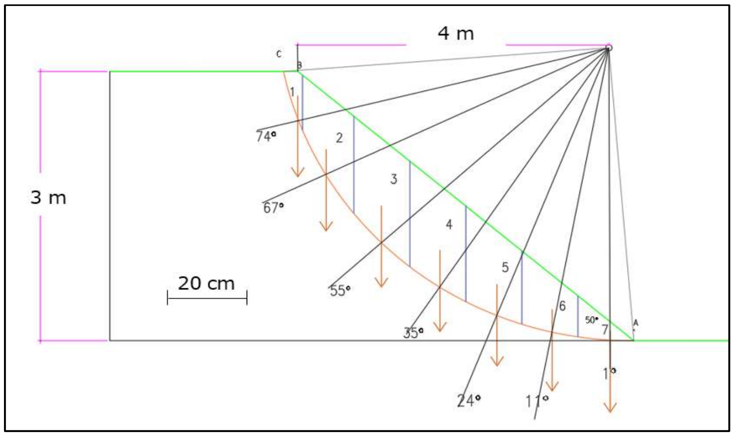

Fig. 6. Slope Failure Trial #1

The calculation step is performed for the entire slice mass and the result is presented in Table 4. Based on Formula (3), Fs for Slope Failure Trial #1 is 1,63. This value is greater than 1,25 as the threshold value explained in Table 1. Thus, the slope considered to have less possibility of landslide.

Table 4
Calculation Summary Slope Failure Trial #1

Slice No. (1)	An (m^2)	W_n (kN/m) (2)	α_n (deg) (3)	$\sin \alpha_n$ (4)	$\cos \alpha_n$ (5)	ΔL_n (m) (6)	$W_n . \sin \alpha_n$ (kN/m) (7)	$W_n . \cos \alpha_n$ (kN/m) (8)
1	0.13	2.08	74	0.9613	0.2756	0.30	2.00	0.57
2	1.04	16.64	67	0.9205	0.3907	0.70	15.32	6.50
3	1.51	24.16	55	0.8192	0.5736	0.65	19.79	13.86
4	1.52	24.32	35	0.5736	0.8192	0.65	13.95	19.92
5	1.25	20	24	0.4067	0.9135	0.70	8.13	18.27
6	0.85	13.6	11	0.1908	0.9816	0.70	2.60	13.35
7	0.36	5.76	1	0.0175	0.9998	0.60	0.10	5.76
						4.30	61.89	78.23

FS = 1.63

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Trial #2 and Trial #3 have been performed following the typical steps in Trial #1. Figure 7 and Figure 8 show the Slope Failure Illustration respectfully. Table 5 and Table 6 show the calculation summary of Trial #2 and Trial #3 respectfully. Fs for Slope Failure Trial #2 is 1,50 while Fs Slope Failure Trial #3 is 1,30.

The result of three Trials shows Fs value greater than 1,25. The average value of Fs based on three Slope Failure Trials is 1,48 is inevitably greater than 1,25. Thus, the slope considered to have less possibility of landslide.

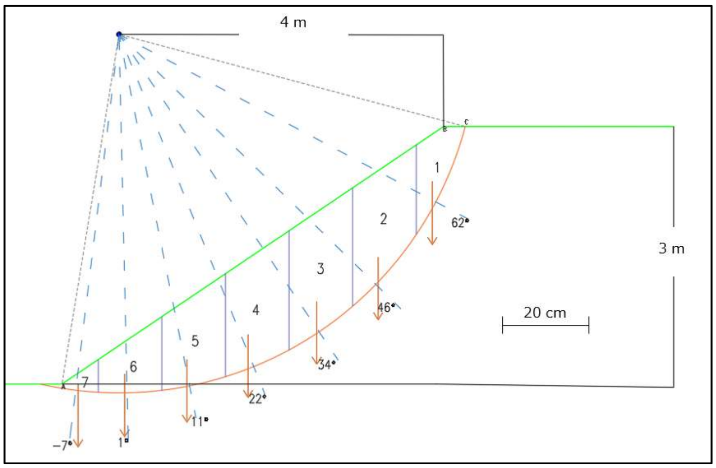

Fig. 7. Slope Failure Trial #2

Table 5
Calculation Summary Slope Failure Trial #2

Slice No. (1)	An (m^2)	W_n (kN/m) (2)	α_n (deg) (3)	sin α_n (4)	cos α_n (5)	ΔL_n (m) (6)	W_n . sin α_n (kN/m) (7)	W_n . cos α_n (kN/m) (8)
1	1.03	16.48	62	0.8829	0.4695	0.60	14.55	7.74
2	3.11	49.76	46	0.7193	0.6947	0.70	35.79	34.57
3	3.56	56.96	34	0.5592	0.829	0.70	31.85	47.22
4	3.33	53.28	22	0.3746	0.9272	0.70	19.96	49.40
5	2.55	40.8	11	0.1908	0.9816	0.70	7.79	40.05
6	1.59	25.44	1	0.0175	0.9998	0.70	0.44	25.44
7	0.27	4.32	-7	-0.1219	0.9925	0.40	-0.53	4.29
						4.50	109.86	208.70

FS = 1.50

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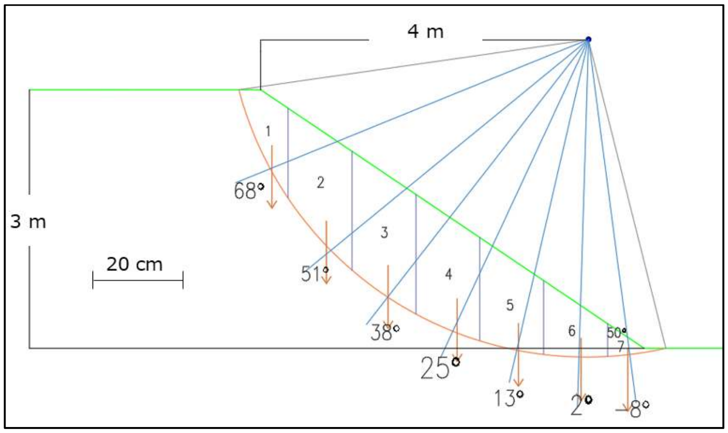

Fig. 8. Slope Failure Trial #3

Table 6
Calculation Summary Slope Failure Trial #3

Slice No. (1)	An (m^2)	W_n (kN/m) (2)	α_n (deg) (3)	sin α_n (4)	cos α_n (5)	ΔL_n (m) (6)	W_n . sin α_n (kN/m) (7)	W_n . cos α_n (kN/m) (8)
1	1.03	16.48	68	0.9272	0.3746	0.60	15.28	6.17
2	3.33	53.28	51	0.7771	0.6293	0.70	41.41	33.53
3	3.85	61.6	38	0.6157	0.788	0.70	37.92	48.54
4	3.11	49.76	25	0.4226	0.9063	0.70	21.03	45.10
5	2.64	42.24	13	0.225	0.9744	0.70	9.50	41.16
6	1.56	24.96	2	0.0349	0.9994	0.70	0.87	24.94
7	0.27	4.32	-8	-0.1392	0.9903	0.40	-0.60	4.28
						4.50	125.41	203.72

FS = 1.30

5. Conclusion

This study has performed three Slope Failure Trials to assume the failure plane of the slope formed by the embankment in reclamation area of the Phase 2A terminal development project of West Java Port. The calculation result by using Simplified Bishop Method is as follow:

a. The result of the Slope Trial #1 show the Fs value is 1.63, while Slope Trial #2 and Slope Trial #3 show the Fs value of 1.50 and 1.30 respectfully. These values are greater than 1,25 as the threshold value of landslide occurrence possibility. Thus, the slope considered

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to have less possibility of landslide.

b. The average value of Fs based on three Slope Failure Trials is 1,48. This value is inevitable greater than 1,25. Thus, the slope considered to have less possibility of landslide.

Thus, the slope in the reclamation area of the Phase 2A Terminal Development project is safe. This result is important to be verified in order to decide the stabilization treatment prior to the commencement of Phase 2B.

6. Implications

The benefit of this study is to contribute to the application of geotechnical science, especially in slope stability areas. This study can provide a deeper understanding to students whom willing to comprehend the basic principles in slope stability and to practice the calculation without software. The result of this study is expected to be a comparison for the project team regarding whom carry out the Phase 2A development.

7. Research limitations

This study has several limitations since no earthquake, liquefaction, nor changes in groundwater levels and sea tides were considered. The aim is to focus on the topic of slope failure analysis based on Simplified Bishop Method. The result of the Fs determination highly depends on the consistency of the drawing scale and slope failure assumptions. The more trials to perform, the more accurate the result to expect.

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