STABLE SLOPE DESIGN BASED ON LIMIT EQULIBRIUM METHOD (LEM) AND FINITE ELEMENT METHOD (FEM) AT PIT X, LAHAT, SOUTH SUMATRA

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ABSTRACT

Coal mining process using open pit mining method is closely related to slope stability. A slope whose stability is disturbed will have a higher potential for landslides. The slope stability analysis in this research is conducted by Limit Equilibrium Method (LEM) with the calculation of Morgenstern-pice slice method and Finite Element Method (FEM) with the calculation of Shear Strength Reduction. The highwall simulation was modeled with a Bench height of 10 meters, Bench width of 6.5 meters and bench tilt angle varying between 30°, 45°, 60° and groundwater condition using steady state FEA. From the results of the LEM analysis on the highwall with a bench tilt angle of 30 °, 45 °, 60 ° has a safety factor value of 1.005; 0.76; 0.584. While the results of the FEM analysis on the highwall with a bench tilt angle of 30 °, 45 °, 60 ° have a Strength Reduction Factor value of 0.98; 0.72; 0.57. Comparison of the safety factor values of the two methods has an average difference of 1-2%. This is because the FEM takes into account the stress-strain in the material which describes how the material behaves. The stable slope design based on LEM is a highwall slope with a Bench slope angle of 22° which has a safety factor value of 1.478 and based on FEM is a highwall slope with a Bench slope angle of 22° which has a Strength Reduction Factor value of 1.42.

Keyword: Slope Stability Analysis, Finite Element Method, Limit Equilibrium Method.

INTRODUCTION

There is always a risk of collapse on a slope. This is because the slope is in an unstable condition. Therefore it is necessary to calculate the stability of the slope in order to prevent landslides or unstable slopes. In calculating the value of slope stability, there are several methods that can be used. These methods include the Limit Equilibrium Method and the Finite Element Method. In the Limit Equilibrium Method, the slope stability condition is expressed in terms of safety factor (SF).

In the Limit Equlibrium Method the factor of safety is calculated using force equilibrium, moment equilibrium, or using both equilibrium conditions. In the Finite Element Method, the slope stability condition is expressed in terms of the Strength Reduction Factor (SRF) index, which is equal to the safety factor value. This method has the principle of reducing the shear strength of the material gradually to form a collapse mechanism. Both methods have differences in the calculation of slope stability, which will affect the value of the slope stability calculation results.

RESEARCH METHOD

This research is a study to determine the comparison of the safety factor values calculated by the Limit Equilibrium Method and the Finite Element Method. In the first stage, secondary data is collected such as laboratory test on samples taken from the borehole. The result of laboratory test is physical properties of rocks such as unit weight and mechanical properties of rocks such as cohesion, friction angle, modulus young, poisson ratio and compressive strength value of rocks.

Table 1. Laboratory Test Results, Physical and Mechanical Properties of Rocks

Material	Ywet(kN/m3)	Sudut Geser Dalam		Kohesi (c (kPa))		Poisson Ratio (μ)	Modulus Young (Ed	UCS (Mpa)
		Peak	Residu	Peak	Residu			
Soil	16,498	20,2	20,2	9,26667	9,26667	0,4	50000	0,051
SS2	20,416	27,2038	7,97	831,377	541,831	0,26625	247,525	1,70305
CS2	21,406	31,5733	12,277	761,926	164,185	0,331	291,367	2,3651
XO1	22,452	24,16	6,15	708,287	205,338	0,246	322,9	1,3684
SS3	21,335	27,08	9,78	76,297	47,6572	0,2495	351	2,2805
CS3	20,977	17,826	6,728	208,364	120.31	0,331	291,367	2,3651
SS4	21,327	20,971	7,793	214,962	90,29	0,2495	351	2,2805
Coal	19,078	23,862	7,37	185,368	86,298	0,4	50000	1,1
CS4	19,699	24,234	10,15	160,524	68,823	0,331	291,367	2,3651
SS5	19,97	29,44	6,27	106,797	100,512	0,2495	351	2,2805
CS5	21,239	22,54	6,536	238,649	93,87	0,331	291,367	2,3651

To determine the subsurface geological conditions, the correlation of borehole data is carried out so that the overburden layers and coal layers that will be analyzed can be known. From the correlation will be made into a subsurface geological model that will later be made slope design adjusting a particular model. Calculation of slope stability is assisted by using Slide2 and RS2 software where the highwall slope is modeled with a Bench height of 10 meters, Bench width of 6.5 meters and Bench tilt angle varies between 30°, 45°, 60°.

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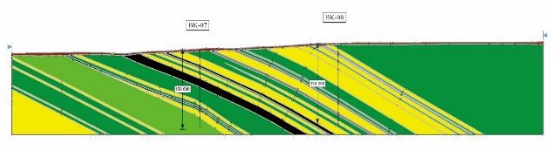

Figure 1. Subsurface Geology Model

In the Limit Equilibrium Method, calculations based on Morgenstern and Price in 1965 are used, where the analysis process is the result of the equilibrium of each normal force and moment acting on each slice of the slope plane. In this method, simplifying assumptions are made to show the relationship between the shear force around the slice (X) and the normal force around the slice (E) with the equation:

$$X = E.\lambda.f(x) \quad \text{.........................}(1)$$

In the Finite Element Method (FEM), the domain of the analyzed area is divided into a number of smaller zones or we can call them elements. The elements are considered interconnected by nodal points. In this method, the calculation to find the factor of safety by reducing the value of the cohesion value (c), and the friction angle (Ø), gradually until the soil collapses. The reduction of the cohesion parameter (c), and the friction angle (Ø) can be expressed by the following equation :

$$C_f = \frac{c}{SRF} \quad \text{.............................}(2)$$

$$\phi_f = tan^{-1}\left(\frac{\tan\phi}{SRF}\right) \quad \text{...............}(3)$$

RESULT AND DISCUSSION

Slope Stability Analysis Using Limit Equilibrium Method

The slope stability analysis in this method uses Mohr Coulomb failure criteria and the Groundwater Condition is steady FEA (Finite Element Analysis). The failure plane uses a circular failure type and the search method uses auto-refine search.

On the highwall slope which has an overall slope angle of 24° and a slope height of 42 meters with the geometry of Bench height of 10 meters, Bench width of 6.5 meters and Bench angle slope of 30° it resulted an SF value of 1,005.

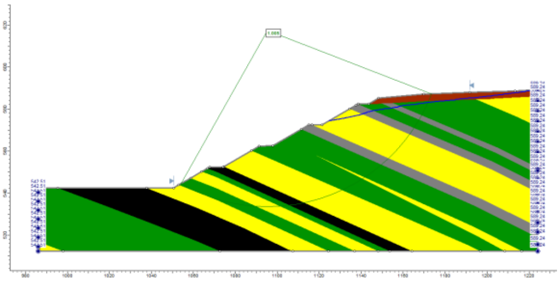

Figure 2. Highwall Slope Stability Analysis with 30° Bench Inclination Angle

Then in the highwall slope which has an overall slope angle of 32 ° and a slope height of 52 meters with the geometry of the Bench height of 10 meters, Bench width of 6.5 meters and the slope of the Bench angle of 45 ° it resulted an SF value of 0.76.

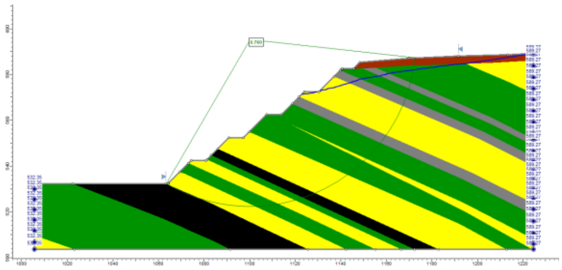

Figure 3. Highwall Slope Stability Analysis with 45° Bench Inclination Angle

And on the highwall slope which has an overall slope angle of 40° and a slope height of 62 meters with the geometry of the Bench height of 10 meters, Bench width of 6.5 meters and the slope of the Bench angle of 60° it resulted an SF value of 0.584.

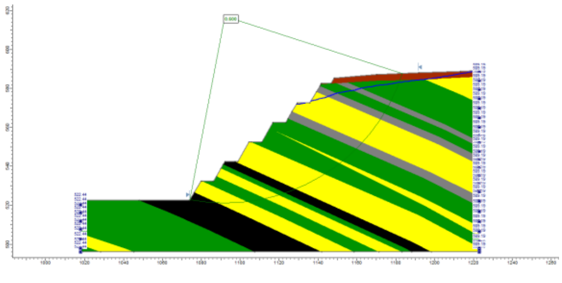

Figure 4. Highwall Slope Stability Analysis with 60° Bench Inclination Angle

The results of the slope stability analysis of the three parameters show the FK value <1.3. Therefore it is necessary to do engineering so that the FK value> 1.3. Engineering is done on the slope geometry where the overall slope angle is changed to 15° and the slope height is 63 meters with the geometry of Bench height of 10 meters, Bench width of 6.5 meters and Bench angle slope of 22°. After the

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slope geometry has been redesign, the SF value changed to 1.478.

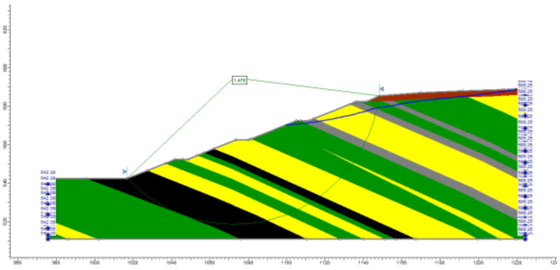

Figure 5. Highwall Slope Stability Analysis with 22° Bench Inclination Angle

Slope Stability Analysis Using the Finite Element Method

The slope stability analysis in this method uses the Shear Strength Reduction method with Mohr coulomb collapse criteria. For the groundwater condition, the Steady State FEA (Finite Element Analysis) setting is used. The failure plane is not assumed in advance because it uses the Shear Strength Reduction approach where the cohesion and friction angle of the material are reduced until it finally collapses and forms a failure plane.

On a highwall slope that has an overall slope angle of 24° and a slope height of 42 meters with the geometry of a Bench height of 10 meters, a Bench width of 6.5 meters and a Bench angle of 30° it resulted an Critical SRF of 0.98.

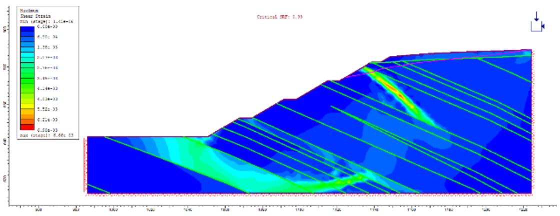

Figure 6. Highwall Slope Stability Analysis with 30° Bench Inclination Angle

Then on the highwall slope which has an overall slope angle of 32° and a slope height of 52 meters with a Bench height geometry of 10 meters, a Bench width of 6.5 meters and a Bench of 45° it resulted an SRF value of 0.72.

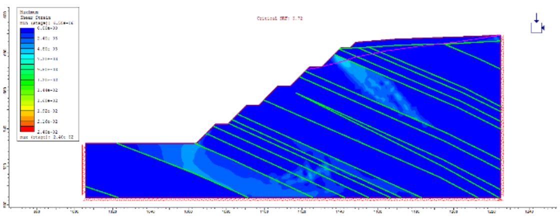

Figure 7. Highwall Slope Stability Analysis with 45° Bench Inclination Angle

And on the highwall slope which has an overall slope angle of 40° and a slope height of 62 meters with the geometry of Bench height of 10 meters, Bench width of 6.5 meters and Bench angle slope of 60° it resulted an SRF value of 0.57.

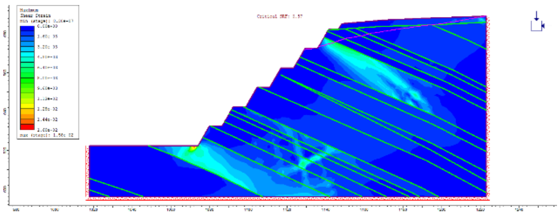

Figure 8. Highwall Slope Stability Analysis with 60° Bench Inclination Angle

The results of the slope stability analysis of the three parameters show the FK value < 1.3. Therefore it is necessary to do engineering so that the FK value> 1.3. Engineering is done on the slope geometry where the overall slope angle is changed to 18° and the slope height is 42 meters with the geometry of Bench height of 10 meters, Bench width of 6.5 meters and Bench angle slope of 22°. After the slope geometry has been redesign, the SF value changed to 1.42.

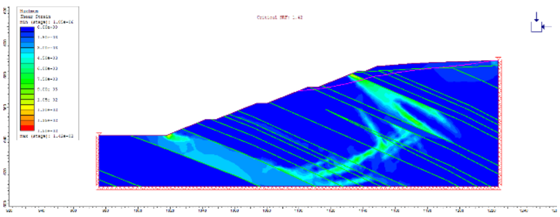

Figure 9. Highwall Slope Stability Analysis with 22° Bench Inclination Angle

Comparison of Slope Stability Analysis Results Using Limit Equilibrium Method and Finite Element Method.

Table 2. Average Percentage Difference in Safety Factor

Bench slope	Safety Factor		Difference (%)
	LEM	FEM	
30	1,005	0,98	1%
45	0,76	0,72	2%
60	0,584	0,57	1%

From the calculation results, it can be said that LEM and FEM have the same factor of safety, with an average difference of less than 1%-2%. However, it can be seen that the slope stability analysis using FEM has more pessimistic results than LEM. This is because the FEM analysis calculate the stress-strain in the material which describes how the material behaves. FEM also analyzes all parts of the slope, while LEM only analyzes the slices with a predetermined failure plane.

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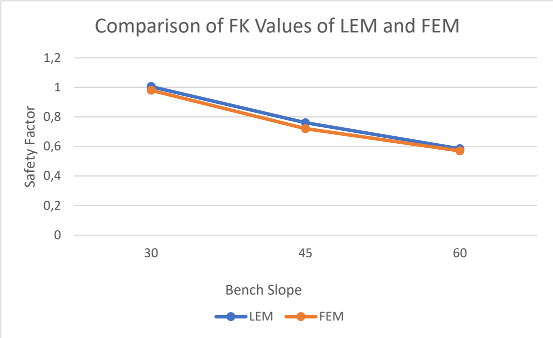

Figure 10. Comparison Chart of Safety Factor Values using LEM and FEM

CONCLUSION

Comparison of Factor of Safety values based on Limit Equilibrium Method (LEM) and Finite Element Method (FEM) has a quite different value with an average difference of 1 - 2%. Where the results of the slope stability analysis using FEM are more pessimistic, because FEM takes into account the stress-strain of the material, and the analysis is carried out on all parts of the slope. Stable slope design based on Finite Element Method (FEM) and Limit Equilibrium Method (LEM) can be done by redesigning the geometry of the highwall slope with a Bench slope angle of 22°.

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REFERENCES

Ardhi, H. A., Azizi, M. A., Marwanza, I., Hartami, P. N., Nugroho, B., & Saptono, S. (2017). Perbandingan Analisis Stabilitas Lereng Metode Kesetimbangan Batas Dengan Metode Elemen Hingga Menggunakan Pendekatan Probabilistik.

Allan Takwin, G.E., Rondonuwu, S. G. (2017). Analisis Kestabilan Lereng Metode *Morgenstern-Price* (Studi Kasus : Diamond Hill Citraland).

Arif, I. (2016). Geoteknik Tambang. Gramedia Pustaka Utama.

Astawa Rai, M., Kramadibrata, S., Wattimena, R. K. (2013). Mekanika Batuan. Penerbit ITB

C Wyllie, D., & W Mah, C. (2004). *Rock Slope Engineering: Civil and Mining, 4th Edition*.

Duncan, J. M. (1996). *State Of The Art: Limit Equilibrium And Finite-Element Analysis Of Slopes*. *Journal Of Geotechnical Engineering,* 122:577.

Gafoer, S., Cobrie, T., & Purnomo, J. (1986). Peta Geologi Lembar Lahat, Sumatra Selatan, Skala 1:250.000. Pusat Survey Geologi.

Gouw, I., Liong, T., Eng, M., Juven, D., & Herman, G. (2012). Analisa Stabilitas Lereng Limit Equilibrium Vs Finite Element Method.

Hammouri, N. A., Husein Malkawi, A. I., & Yamin, M. M. A. (2008). *Stability Analysis Of Slopes Using The Finite Element Method And Limiting Equilibrium Approach*. *Bulletin of Engineering Geology and the Environment*, *67*(4), 471–478.

Hutahayan, P. P., & Trides, T. (2018). Analisis Pengaruh Airtanah Terhadap Kestabilan Lereng Menggunakan Finite Element Method Pada PT. Bharinto Ekatama, Kabupaten Kutai Barat Kalimantan Timur. Jurnal Teknologi Mineral FT UNMUL (Vol. 6, Issue 2).

Jalil, A. (2011). *The Analysis Slope Stability Reservoir Keuliling with Finite Element Methods*. Jurnal Teknik Sipil, 18(3), 239.

Jamaluddin., Cheng, F. (2018). *Organic Richness and Organic Matter Quality Studies of Shale Gas Reservoir in South Sumatra Basin, Indonesia*. *Journal of Geoscience and Environment Protection*, *06*(12), 85–100.

Keputusan Menteri ESDM Nomor 1827 K/30/MEM/2018. (2018). In *Kementerian Energi dan Sumber Daya Mineral*.

Matsui, T., San, K. (1992). *Finite Element Slope Stability Analysis By Shear Strengh Reduction Technique. Japanese Society of Soil Mechanics and Foundation Engineering.* Vol.32, No1, 59-70.

Morgenstern, N. R., Price, V. E., George, G., & London, S. (1996). *The Analysis Of The Stability Of General Slip Surfaces. The Institution of Civil Engineers.* Vol 15, No 1.

E-ISSN : 2579 – 3136

Riza, M. (2018). *Reliability Of Finite Element Method And Limit Equilibrium Method In Stability Analysis Of Dam*.

Ruslan Loilatu, & Iswandaru. (2022). Analisis Kestabilan Lereng Andesit Menggunakan Metode FEM pada PT. X. *Jurnal Riset Teknik Pertambangan*, 15–23.

Read, J., Stacey, P., & Read Peter Stacey, J. (2009). *Guide Line for Open Pit Slope Design*.

Setiawan, B., & Samudera, T. (2018). Analisis kestabilan lereng dengan menggunakan metoda RMR, SMR dan kesetimbangan batas pada tambang terbuka di Kabupaten Belitung Timur.

Sulistyowati, T., Agustawijaya, D. S., Muchtaranda, I. H., Prabowo, A., & Ngudiyono, D. (2022). Simulasi Beban Runtuh Lereng Dengan Metode Elemen Hingga Menggunakan Program Abaqus Se (Studi Kasus Lereng Villa Senggigi). Jurnal Konstruksia. (Vol. 13).

Wulandari, S. (2017). Analisis Stabilitas Lereng Dengan Metode Kesetimbangan Batas (*Limit Equilibrium*) Dan Elemen Hingga (*Finite Element*). Jurnal Desain Konstruksi. Volume 16, No 1.

Zakaria, Z. *(2011).* Analisis Kestabilan Lereng Tanah. Program Studi Teknik Geologi Fakultas Teknik Geologi. Universitas Padjajaran

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