

RESEARCH ARTICLE

Sensitivity Analysis of Phase 5 Batu Hijau Pit Walls

Khatib Syarbini¹, Andi Faesal^{1,*}, Za Munarfan Putra¹, Syamsul Hidayat², Wahyu Hermansyah¹,
Melinda Dwi Erintina², Aji Syailendra Ubaidillah², Iwan Dermawan¹, Uraihan Azhari²,
Muhammad Samsul Hakim¹

¹Geological Engineering Department, Universitas Muhammadiyah Mataram, 83115 Mataram City, Indonesia
²Mining Engineering Department, Universitas Muhammadiyah Mataram, 83115 Mataram City, Indonesia

* Corresponding author : andi.esal@gmail.com
Tel.: +6281802727076;
Received: Feb 25, 2025; Accepted: May 31, 2025.
DOI: 10.25299/jgeet.2025.10.02.21571

Abstract

The Batu Hijau mine, an extensive copper-gold operation in West Sumbawa, Indonesia, employs an open-pit mining method and is characterized by its significant pit dimensions, with planned slope heights reaching up to 1000 meters. Given the scale of the operation, maintaining slope stability is critical, influenced by stress on the pit slopes, geological structures, mine geometry, and rock mass strength. This study investigates the impact of groundwater on slope stability, emphasizing the role of groundwater pressure in reducing shear strength and consequently affecting slope stability.

A comprehensive sensitivity analysis was conducted to evaluate the influence of groundwater pressures on the stability of the Batu Hijau pit walls. This analysis utilized the SLIDE® software from Rocscience, incorporating Rock Mass Rating parameters derived from geotechnical drill hole logs and mapping data, which were integrated into a 3D block model using Minesight™. The analysis focused on two groundwater conditions: Water Surface and Pore Pressure Grid. Groundwater model conditions were based on piezometer data and a new groundwater conceptual model of the Batu Hijau pit walls.

Results from sensitivity assessments shows that high pore pressure will decrease the slope stability. This findings highlight the need to manage groundwater pressures within the pit walls to mitigate slope instability effectively, therefore, the safety of mining operational could be increased. This study provides valuable insights into groundwater pressure management and its implications for slope stability in large-scale open-pit mining operations.

Keywords: Batu Hijau, Rock Mass Rating, Groundwater, Water Pressure, Rock Mass

1. Introduction

The presence of groundwater in the rock slope surrounding an open pit adversely affects slope stability due to the following reasons (Pantelidis, 2009):

1. *Water pressure* within rock mass discontinuities decreases shear strength. In tension cracks or near-vertical fissures, water pressure reduces stability by increasing the force that promotes sliding.
2. Changes in *moisture content* in certain rocks, especially shales, can lead to accelerated weathering, resulting in decreased stability.
3. During winter, the *freezing* of surface water on slopes can obstruct drainage paths, leading to a buildup of water pressure within the slope and subsequently reducing its stability.
4. The velocity of groundwater flow can cause the *Erosion* of fissure infillings, leading to a reduction in stability.

Given these conditions, the most significant impact of groundwater in the rock mass is the reduction in stability due to water pressure within the rock discontinuities (Ucar et al, 2023).

The pore pressure which resulted from the trapped water behind the pit walls has more significant impact to the pit wall compared to the normal phreatic surface (Kausarian et al, 2023), because the trapped water could give more pressure to the wall surface, therefore it should be modelled properly (El-Idrissy, 2013). As numerous large-scale open-pit mines approach their operational thresholds, these limits are frequently dictated by constraints related to slope stability

influenced by groundwater conditions (McKelvey et al., 2002). This situation is evident in the Batu Hijau pit walls, which are becoming deeper and steeper (Clode, 1999). Currently, the Batu Hijau pit walls have reached heights of 400 to 500 meters, with inter-ramp angles ranging from 37 to 45 degrees.

Sensitivity analysis needs to be conducted in order to assess the effect of groundwater pressures (Maji & Sitharam, 2018) and also to determine the maximum groundwater pressure to be maintained to keep the stability of the pit walls (Davi & Hutahayan, 2021).

2. Geology Of Batuhijau

The lithology of the Batu Hijau area comprises andesite volcanic rocks and volcanoclastic sediments (Faesal et al, 2022). These rocks intrude and cover most of the pit area (Sillitoe & Hedenquist, 2003). In the northeastern part of the mine, this sequence is intruded by a quartz diorite (Arif & Baker, 2004) (Figure 1). Along the contact between the volcanic rocks and diorite, multiple tonalite porphyries have intruded, with most of the mineralization linked to the earlier tonalite intrusions and higher intensity quartz veining (Leech & McGann, 2007). Extensive hydrothermal alteration has overprinted the basic lithology as part of the mineralization process (Sillitoe, 2010).

In Batu Hijau, the identified structural patterns are oriented west-northwest (W-NW), north-northeast (N-NE), and include some dips from the main faults (Priowasono and Maryono, 2002). The Tongoloka-Puna fault zone, located southwest of the ore body center (Adriansyah et al, 2018), is

approximately 600 meters long with a west-northwest orientation and a dip angle between 60° and 70°. Meanwhile, to the northeast lies the Katala fault zone, which is approximately 525 meters long with a west-northwest orientation and a dip angle of 67° towards the northeast (Adriansyah et al, 2015). The Nono and Bambu fault zones are situated to the northwest, with a north-northeast orientation and a dip angle of 75° towards the west-northwest (. The southern boundary is located in the southeastern part of the deposit, with a north-northeast orientation and a dip angle of 75°-80° towards the southeast (Ali, 1997).

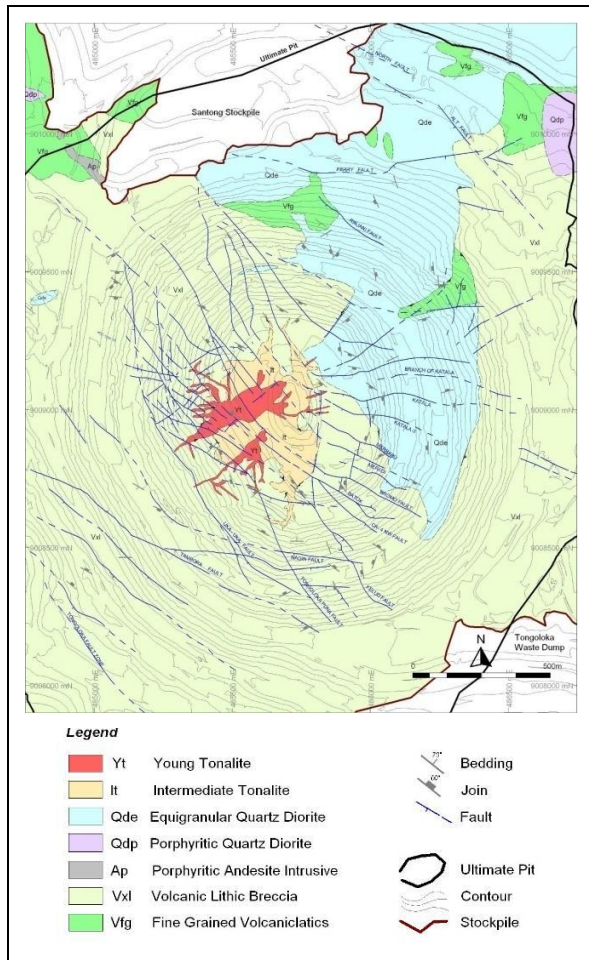


Fig 1. Geology of Batu Hijau deposit (Geology Department PT.NNT, 2010)

3. Data Sources and Methodology

The data of rock mass properties were collected from geotechnical and geological data bases meanwhile groundwater data were collected from the instrumentations that were installed surrounding the pit.

The rock mass strength properties were estimated by using Geological Strength Index (GSI), Uniaxial Compressive Strength (UCS), Intact Rock Constant (mi) and Disturbance Factor (D) (Hoek and Bray, 1981). Those parameters are defining the Hoek-Brown Strength Criteria (Hoek and Brown, 2018). The Hoek-Brown criterion has been chosen for the stability analysis because this criterion is the most suitable for the rockmass condition at Batu Hijau site.

Rock Mass Rating (RMR) (Bieniawski's, 1989) was determined with the parameter recorded from geotechnical drill hole logs and mapping data. The output used in the generated of a Minesight™ based 3D block model to

reproduce a good representation of the rock mass characteristics of the Batu Hijau deposit.

The groundwater condition is not a normal hydrostatic groundwater, but it is trapped at some compartments of which each compartment is a closed area (Gkiougkis et al, 2021) which is controlled by some structures which act as an impermeable barrier; therefore, the groundwater model conditions considered for analyses were groundwater elevations from piezometric (Zaadnoordijk et al, 2019) data interpretation and secondly groundwater pressure distributions based on a new conceptual model (Beale, 2009).

The current situation for pore pressure in the pit slopes was summarized by Geoff Beale (Shlumberger Water Services). He stated that based on the observed piezometer data, groundwater pressure distributions at the Batu Hijau pit could not realistically be modeled using simple phreatic surfaces as input into geotechnical models (Beale, 2013). The pore pressure distributions are more complex, and they are illustrated in the model (Figure 2).

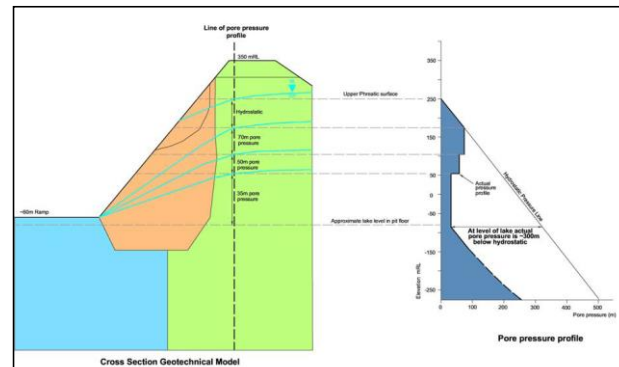


Fig 2. Illustration of the hydrostatic distribution in Batu Hijau pit walls (Geoff Beale – Technical Memorandum October 2009)

The groundwater pressure profile shown in Figure 2 indicates that there is an increase of hydrostatic pressure with depth from the 0 pressure to 70m. At this depth, the groundwater pressure remains constant at 70m (700 KPa) and down to around 100 mRL where it reduces to 50m pressure (500 KPa) and remains constant for another 50m in depth. A subsequent reduction in groundwater pressure from 50m to 35m occurs at around 50 mRL and remains constant until it reaches the depth of the pit lake. From then on the groundwater pressure increases hydrostatically (Abd Karim et al, 2020).

The slope stability analysis method used was Limit Equilibrium Analysis using SLIDE® application from Rocscience, where the parameters which were considered for analysis as follow:

- Strength type: Generalized Hoek & Brown criteria
- Ground water method: Water surfaces and grid pore pressure
- The gridsearch for slip surface: Circular.

4. Stability Assessments

The assessments were carried out by two groundwater conditions, namely Water Surface and Pore Pressure Grid (Melnikova et al, 2014).

4.1 Water Surface

Piezometric data in the pit showed different water elevations at different locations of the same section of the pit (Beale, 2009). The water surfaces represented in the analysis section were using a single water table line and piezometric lines. The illustration of groundwater surface is interpreted based on groundwater model in Figure 3.

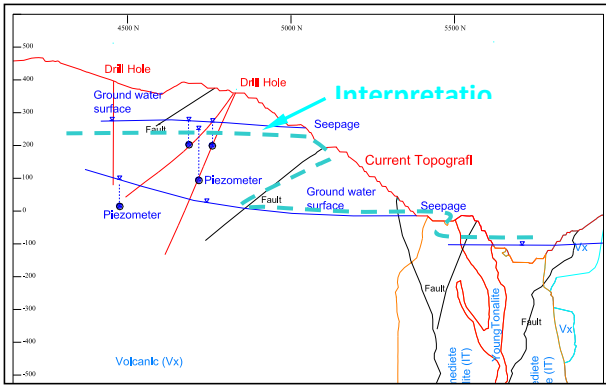


Fig 3. Interpretation of groundwater surface in Batu Hijau pit wall (section 270° as an example).

4.2 Pore Pressure Grid

The pore pressure grid model used represented groundwater pressure distributions as described in the previous chapter. A grid was generated with groundwater pressure values to simulate the pressure distributions within the section. The illustration of groundwater pressure distributions is presented in Figure 4.

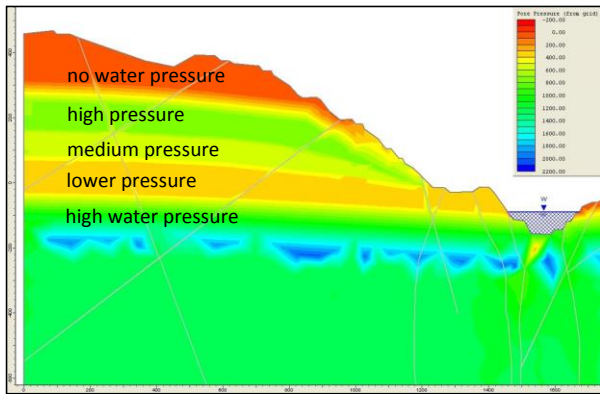


Fig 4. Illustration of groundwater pressure distributions in Batu Hijau pit wall. It shows that the pressure distribution is unique, higher pressure at the upper area and lower pressure at the lower area (Section 270° as an example).

A series of analyses was conducted for both groundwater conditions above to investigate the groundwater impact to the stability of the pit walls. The initial results of these analyses were reviewed by Geoff Beale and his recommendations were undertaken in order to assess the pore pressure sensitivity.

1. One scenario where the area of low groundwater pressure was removed, and the pressure “bands” continued all the way into the slope.
2. A second scenario where the low groundwater pressure area was substituted with an area of 20 m (200 kPa) for the first 40 m behind the slope, and 70 (700 kPa) was over the rest of the slope.
3. A third scenario where the low groundwater pressure area was substituted with an area of 35 m (350 kPa) for the first 40 m behind the slope, and 100 (1,000 kPa) groundwater pressure was over the rest of the slope.

When the scenario one was run, the results of FoS were extremely low in the range of 0.2 -0.4 (see Figure 5 as an example). Considering that the slope is currently stable this scenario was not investigated further.

When the second scenario was run at the same section as the first scenario, the FoS were still low in the range of 0.8 – 1. In addition, when the third scenario was run, the resultant FoS were still very low.

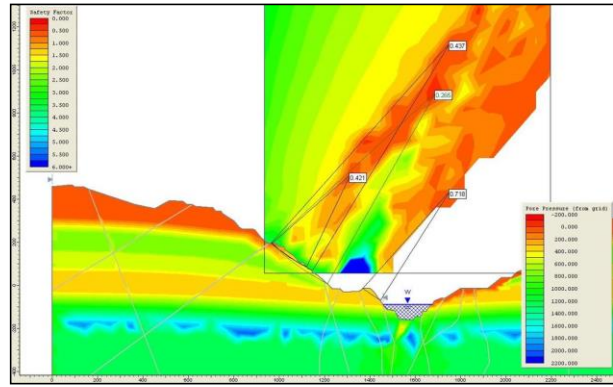


Fig 5. Analysis result for scenario 1 in section 270° as an example.

In order to represent the recommendations above, four groundwater pressures were modeled in the first 40m behind slopes: 100 kPa, 150 kPa, 200 kPa and 250 kPa.

5. Stability Analysis Result

The analysis results are presented in Table 1 and Table 2 for the cases of water table method and pore pressure grid method respectively.

5.1 Water Table and Piezometric Line Results

Table 1 shows the FoS result for water table and piezometric line methods. The range of FoS for water table method are between 1.553 to 2.236 and for the piezometric line are between 1.598 to 5.214.

Table 1. Stability analyses results for water surface method

No	Slope Section	FoS		Variance
		Water Table	Piezometric line	
1	000°	1.797	1.797	0.000
2	030°	1.580	1.598	0.018
3	090°	1.553	1.706	0.153
4	135°	2.154	2.824	0.670
5	180°	2.236	5.214	2.978
6	210°	2.175	2.261	0.086
7	270°	1.857	2.149	0.292
8	315°	2.154	2.327	0.173

Table 2. Stability analyses results for pore pressure grid method

No	Slope Section	FoS	FoS	FoS	FoS
		Surface pressure 100 kPa	Surface pressure 150 kPa	Surface pressure 200 kPa	Surface pressure 250 kPa
1	000°	1.776	1.771	1.765	1.749
2	030°	1.593	1.592	1.591	1.232
3	090°	1.508	1.488	1.377	1.157
4	135°	1.508	1.205	0.781	0.389
5	180°	2.099	1.664	1.111	0.984
6	210°	1.362	1.249	1.117	0.66
7	270°	1.568	1.336	0.814	0.595
8	315°	1.557	1.318	1.207	0.889

These methods give high FoS in all cases (above 1.2, minimal FoS required) because hydrostatic groundwater pressure is only applied when it reaches the groundwater surface. Therefore, even though the pressure is very high at the lower parts of the section, no pressure is applied close to the failure surface. The FoS variance between these methods are in the range of 0 to 2.978.

The difference between these two methods is that only one piezometric line can be applied to a selected material while the continuity of the water line will vary the groundwater pressures across the same material.

The analysis results of water table and piezometric line method are presented in Figure 6 and Figure 7.

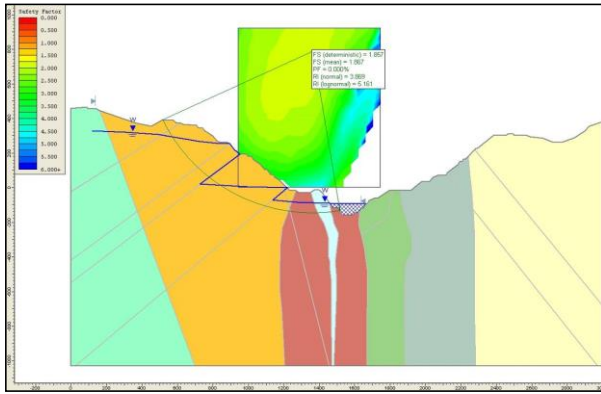


Fig 6. Analysis result for water table method in section 270° as an example.

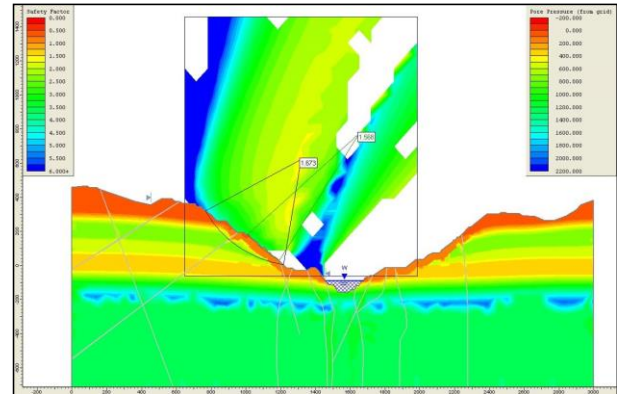


Fig 8. Analysis result for pore pressure grid method with 100 kPa surface pressures.

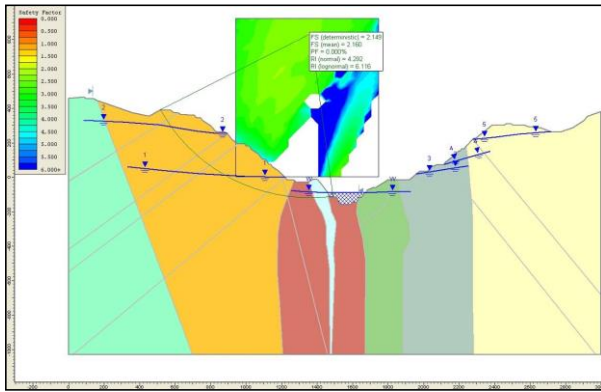


Fig 7. Analysis result for piezometric line method in section 270° as an example.

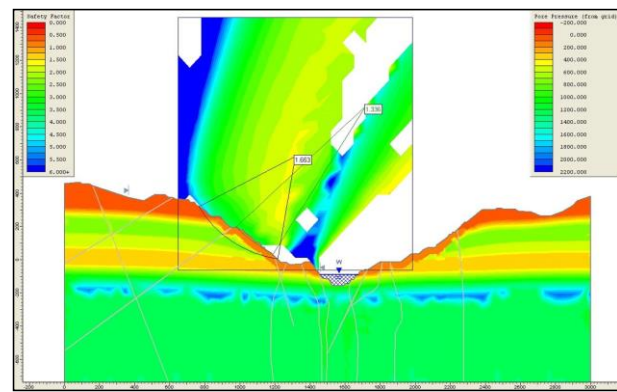


Fig 9. Analysis result for pore pressure grid method with 150 kPa surface pressures.

5.1 Pore Pressure Grid Results

Table 2 shows the FoS for pore pressure grid method. The FoS range are from 1.362 to 2.099 (for surface pressure 100 kPa), 1.205 to 1.771 (surface pressure 150 kPa), 0.781 to 1.765 (surface pressure 200 kPa) and FoS range from 0.389 to 1.749 (surface pressure 250 kPa). The failure mode for this method is predominantly shallow following the water pressure impact on the wall which is more significant on the area close to the surface.

The FoS for section 000, 030 and 090 keep relatively unchanging for groundwater surface pressure from 100kPa to 250 kPa because the water surface is applied only to the lower part of the pit wall. These sections present low water tables while the other sections respond with a decrease in FoS when increasing groundwater pressure.

Table 3. Variance of FoS results for pore pressure grid method

No	Slope Section	Variance 100 kPa - 150 kPa	Variance 150 kPa - 200 kPa	Variance 200 kPa - 250 kPa
1	000°	-0.005	-0.006	-0.016
2	030°	0.001	-0.001	-0.359
3	090°	-0.020	-0.111	-0.220
4	135°	-0.303	-0.424	-0.392
5	180°	-0.435	-0.553	-0.127
6	210°	-0.113	-0.132	-0.457
7	270°	-0.232	-0.522	-0.219
8	315°	-0.239	-0.111	-0.318

Table 3 shows the variance of FoS for increasing pore pressure for each 50 kPa within the pit slopes. The variance range is 0.001 to 0.553.

The analysis results of pore pressure grid method are presented in Figure 8 – Figure 11 (all these figure are presenting the section 270 as the example).

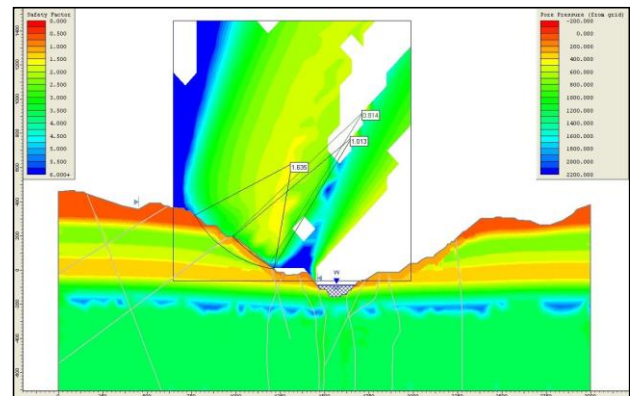


Fig 10. Analysis result for pore pressure grid method with 200 kPa surface pressures.

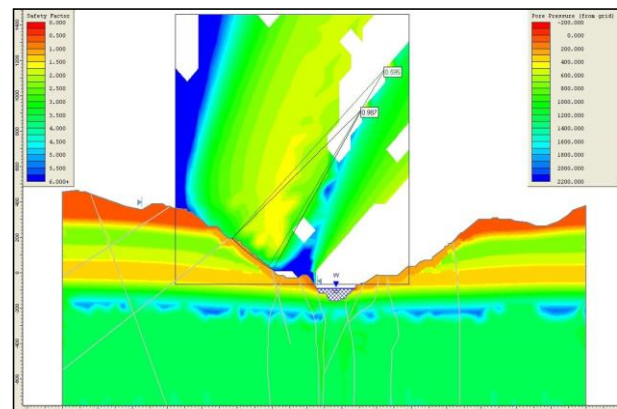


Fig 11. Analysis result for pore pressure grid method with 250 kPa surface pressures.

6. Conclusion And Recommendation

6.1 Conclusion

The analyses results indicate that groundwater has a big influence in the stability of the pit slopes. The most significant impact shown in section 135° and section 270°. It shows that the FoS decreases from 1.508 to 0.389 once the pressure increases from 100 kPa to 250 kPa in section 135°. Meanwhile, section 270° shows that the FoS decreases from 1.568 to 0.595 once the pressure increases from 100 kPa to 250 kPa. Detail results are presented in Table 2 and Table 3.

By decreasing groundwater pressure, Factor of Safety increases significantly. It means the groundwater pressure within the pit walls has to be maintained as low as possible for the walls to remain stable.

The analyses indicate that if groundwater pressures act behind the wall, this pressure cannot exceed 200 kPa since the pit walls will have a FoS below unity.

The analyses also show that there is a big difference in FoS for each type of analysis; water surface method and pore pressure method. The suitable method to be applied for analysis depends on the groundwater regime condition acting on the wall.

It seems that groundwater pressure within the slope is not as simple as hydrostatic distribution but a combination of pore pressure close to the pit wall and a phreatic surface behind it (refer to Geoff Beale's model).

The position of the failure surface is different for each method. For water pressures which are close to the pit wall the failure surfaces appear closer (shallower) than that of the ground water line and piezometric levels.

6.2 Recommendation

Groundwater pressure within the pit walls has to be maintained as low as possible for the walls to remain stable. "Dewatering Well" and "Depressurization Program (Horizontal Drains Drilling Program)" are suggested as the best methods to reduce the pressure of the groundwater. These programs need to be conducted to maintain the low pressure in the pit walls.

Groundwater pressures in the pit walls need to be verified by installing more vibrating wire piezometers.

Implementing those programs require high cost, however, "do-nothing" is not a good choice because potential pit wall failures, if the pore pressure is ignored, could be very significant e.g. lost production, property damage, etc.

Acknowledgements

Thanks to PT Amman Mineral Nusa Tenggara for its approval to publish this paper, also thanks to Mr. Raimundo Almenara for reviewing the analyses result and for all geotech team who contribute and assist in the preparation of this paper.

References

Abd Karim, A. A., Wilopo, W., Indrawan, I. G. B., & Adriansyah, Y. (2021). Estimating of Maximum Groundwater Level to Trigger Landslide in Batu Hijau Open Pit Mine, West Nusa Tenggara, Indonesia. *Journal of Applied Geology*, 6(1), 1–10. <https://doi.org/10.22146/jag.58135>

Adriansyah, Y., Muslim, D., Zakaria, Z. (2015). Risk Analysis of a Major Pit Slope Failure at the Batu Hijau Open Pit Mine Operation PT Newmont Nusa Tenggara. In: Lollino, G., Manconi, A., Guzzetti, F., Culshaw, M., Bobrowsky, P., Luino, F. (eds) *Engineering Geology for Society and Territory - Volume 5*. Springer, Cham. https://doi.org/10.1007/978-3-319-09048-1_140

Adriansyah, Y., Zakaria, Z., Muslim, D., & Hirnawan, F.

(2018). Determining of Geotechnical Domain Based on Joint Density and Fault Orientation at Batu Hijau Mine, West Sumbawa-Indonesia. *International Journal of Engineering*, 31(4), 679–683. DOI: 10.5829/ije.2018.31.04a.21

Ali, E. 1997. Batu Hijau Porphyry Copper-Gold Deposit- Exploration and Evaluation. Kumpulan karya ilmiah Ikatan Ahli Geologi Indonesia (IAGI), Pertemuan Ilmiah Tahunan Ke XXVI, 9-11 Desember. Jakarta, Indonesia

Arif, J., Baker, T. (2004) Gold paragenesis and chemistry at Batu Hijau, Indonesia: implications for gold-rich porphyry copper deposits. *Mineralium Deposita*, 39 (5). 523-535 doi:10.1007/s00126-004-0433-0

Beale, G., (2009) Technical Memorandum, Review of Hydrogeology and Pit Slope Drainage Program, Schlumberger Water Service, Denver, USA

Beale, G (2013), 'Water and slope stability – the application of a new science', in PM Dight (ed.), *Slope Stability 2013: Proceedings of the 2013 International Symposium on Slope Stability in Open Pit Mining and Civil Engineering*, Australian Centre for Geomechanics, Perth, pp. 43-53, https://doi.org/10.36487/ACG_rep/1308_0.3_Beale

Bieniawski, Z.T. (1989) *Engineering Rock Mass Classifications: A Complete Manual For Engineers And Geologists In Mining, Civil, And Petroleum Engineering*. John Wiley & Sons

Clode, C. (1999) "Relationships of intrusion, wall-rock alteration and mineralisation in the batu hijau copper-gold porphyry deposit", in *Proceedings Pacrim Congress*, 10-13 October 1999, Bali, Indonesia, Australasian Institute of Mining and Metallurgy. Vol., No. Issue, (1999), 485-498.

Davi, S & Hutahayan, P.P. (2021). Groundwater Effect on Slope Stability in Open Pit Mining: a Case of West Kutai Regency, East Kalimantan, Indonesia. *Journal of Geoscience Engineering Environment and Technology* 6(4):192-205. DOI: 10.25299/jgeet.2021.6.4.6226

El-Idrissy, H. (2013). Approach to groundwater and pore water pressure modelling for different geotechnical conditions in open pit slope stability analysis. *Proceedings of the 2013 International Symposium on Slope Stability in Open Pit Mining and Civil Engineering*, Australian Centre for Geomechanics, Perth, pp. 433–443. https://doi.org/10.36487/ACG_rep/1308_27_Idrissy

Faesar, A., Aminuddin, M. I. K. A., and Ubaidillah, A. S. (2022). Host rock petrology, hydrothermal alteration characteristics & ore mineralogy of porphyry copper-gold deposit, Brambang, Lombok, West Nusa Tenggara Indonesia. *Mater. Today Proc.* 66, 3071–3076. doi:10.1016/J.MATPR.2022.07.373

Geology Department PT.NNT, (2010) *Quarterly Geology Compilation Map*, PT. NNT, Batu Hijau, Indonesia

Gkiougkis, I., Pouliaris, C., Pliakas, F.-K., Diamantis, I., & Kallioras, A. (2021). Conceptual and Mathematical Modeling of a Coastal Aquifer in Eastern Delta of R. Nestos (N. Greece). *Hydrology*, 8(1), 23. <https://doi.org/10.3390/hydrology8010023>

Hoek, E., and Bray, J.W. (1981) *Rock Slope Engineering*. Revised 3rd Edition, The Institution of Mining and Metallurgy, London, 341-351

Hoek, E., Brown, E.T. (2018). The Hoek-Brown failure criterion and GSI e 2018 edition, *Journal of Rock Mechanics and Geotechnical Engineering*,

- <https://doi.org/10.1016/j.jrmge.2018.08.001>
- Kausarian, H., Aldila, S., Batara, Eka Putra, D.B., Mairizki, F. (2023). Slope Stability Analysis Using the Rock Structure Rating (RSR) Method and Atterberg Limit at Riau - West Sumatra Cross road Km 165 Harau Subdistrict, Lima puluh Kota Regency, West Sumatra Province, Indonesia. *Journal of Geoscience, Engineering, Environment, and Technology* Vol 8 No 2 2023. DOI: //10.25299/jgeet.2023.8.2.14459
- Leech, S. & McGann, M. (2007) Open pit slope depressurization using horizontal drains—a case study newmont. https://www.imwa.info/docs/imwa_2008/IMWA2008_035_Leech.pdf. Accessed 12 Jun 2024
- Maji, V., & Sitharam, T. G. (2008). Sensitivity analysis of pit slope stability for a large coal mine. *Engineering Geology*, 96(3–4), 179–193. <https://doi.org/10.1016/j.enggeo.2007.11.008>
- McKelvey, P., Beale, G., Taylor, A., Mansell, S., Mira, B., Valdivia, C., Hitchcock, W. (2002). Depressurization of the north wall at the Escondida Copper Mine, Chile. Geological Society, London, Special Publications 198, 107–119. <https://doi.org/10.1144/GSL.SP.2002.198.01.08>
- Melnikova, N.B., Jordan, D., Krzhizhanovskaya, V.V., Sloom, P.M.A. (2014) Slope Instability of the Earthen Levee in Boston, UK: Numerical Simulation and Sensor Data Analysis. *Computational Engineering, Finance, and Science*. <https://doi.org/10.48550/arXiv.1401.7631>
- Pantelidis, L. (2009). Rock slope stability assessment through rock mass classification systems. *International Journal of Rock Mechanics and Mining Sciences*, 46(2), pp.315-325 doi.org/10.1016/j.ijrmms.2008.06.003
- Priowasono, E. and Maryono, A. 2002. Structural Relationships and Their Impact on Mining at The Batu Hijau Mine, Sumbawa, Indonesia. *Prosiding Pertemuan Ilmiah Tahunan IAGI ke-31*. Surabaya
- Sillitoe, R.H. and Hedenquist, J.W. (2003) Linkages between Volcanotectonic Settings, Ore-Fluid Compositions, and Epithermal Precious Metal Deposits. *Society of Economic Geologists Special Publications*, No. 10, 315-343.
- Sillitoe, R. H. (2010). Porphyry copper systems. *Economic Geology*, 105(1), 3–41. <https://doi.org/10.2113/gsecongeo.105.1.3>
- Úcar, R., Belandria, N., Corredor, A., & Arlegui, L. (2023). Planar Slope Failure in Heavily Jointed Rock: Tension Cracks and Nonlinear Strength. *Geotech Geol Eng.* 42:1471–1486 doi.org/10.1007/s10706-023-02629-9
- Zaadnoordijk, W, J., Bus, S, A, R., Lourens, A., Berendrecht, W, L. (2019). Automated Time Series Modeling for Piezometers in the National Database of the Netherlands. *Groundwater* Volume 57, Issue 6: Special Section on Time Series Analysis. <https://doi.org/10.1111/gwat.12819>



© 2025 Journal of Geoscience, Engineering, Environment and Technology. All rights reserved. This is an open access article distributed under the terms of the CC BY-SA License (<http://creativecommons.org/licenses/by-sa/4.0/>).