JKSUES-Determination of Mine Waste Dump Material Properties

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DETERMINATION OF MINE WASTE DUMP MATERIAL PROPERTIES THROUGH BACK ANALYSIS

Abstract

Determining properties of mine waste dump material is very difficult due to the difference in dimension between the laboratory equipment and the items to be analyzed. This study aimed to use geotechnical back analysis on past landslides in a bid to determine the parameters of mine waste geomechanics that are similar to the actual field conditions. The technique is based on a trial and error concept which focuses on landslide geometry and conducted by varying the cohesion and friction angle until the safety factor was less than 1.0. The laboratory results showed a 66.230 kPa change as well as a 48.774° friction angle deviation in mine waste dump material properties, while the back analysis indicated 33.735 kPa and 27.352°. This means that there is a reduction in these values, therefore, an increase in these properties is expected to allow the redesign of heap stability.

Keywords: Waste Dump, Back Analysis, Slope Stability,

1. Introduction

Geotechnical parameters are important to stability analysis, but a wide gap is currently between the laboratory test results and the actual field conditions due to the limited dimension of the measuring equipment. Therefore, back analysis is required to bridge this aperture as well as to determine the properties of the rock in case of failure.

In the forward analysis, mechanical properties including displacement producing factors such as stress and strain are translated into safety elements, while back analysis uses a back-calculation process to obtain rock parameters and requires tensile properties such as displacement, stress, and strain to determine the factors of the material including cohesion, friction angle, Young modulus, and Poisson ratio as reported in Fig.1 by Sakurai (2017).

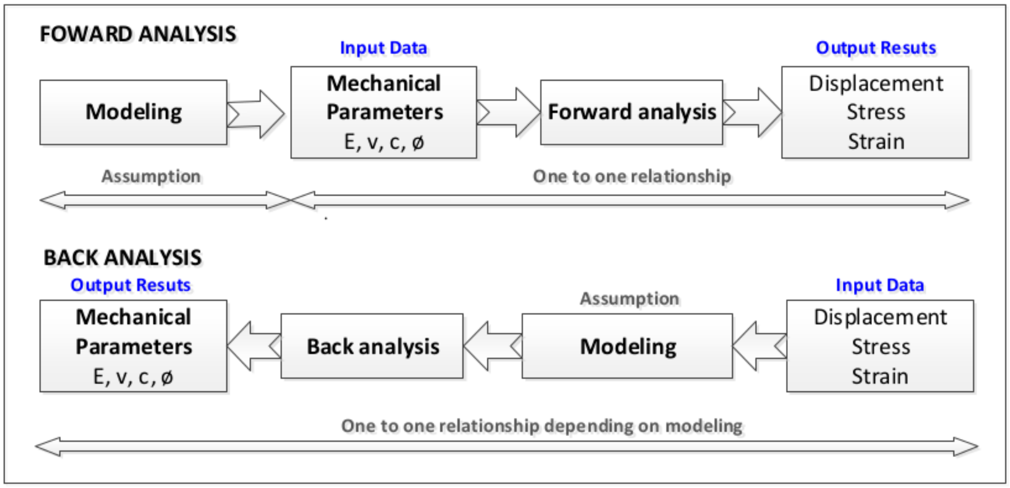


Fig. 1. Difference between forward and back analyses (Sakurai, 2017).

The properties of montmorillonite materials in the coal bottom layer were determined through back analysis and this involved the adjustment of the cohesion and internal friction angle values according to the real field conditions (Rachmad et al., 2020). Meanwhile, the properties of the granular-to-coarse rockfill dump materials were determined using a large triaxial test, but this method did not provide detailed results for substances with high heterogeneity to the boulder (including clay and silt) even with a reduction in friction slope and normal effective pressure (Linero et al., 2007). Therefore, geotechnical evaluation was combined with the 2D finite element method to obtain optimum heap slope stability due to the inadequacy of only the laboratory test (Kainthola et al., 2011). It is also important to understand the geological conditions such as morphology, genesis, alteration, and structure through sample selection to reflect field conditions (Wesley et al., 2019). The determination of the physical and mechanical properties is a very difficult process which requires several approaches and also mandatory to ascertain mine immovability (Öztürk et al., 2015; Rahul et al., 2015; Barritt et al., 2016). According to Mackenzie et al. (2016), the rock geological condition technique has the ability to verify the properties of rock materials, but it is observed not to be suitable for other waste dump materials such as clay and silt (Zovodni et al., 1984). On the other hand, the Kalman filter method continually applies finite elements for this evaluation (Tamara et al., 2014). Therefore, the variations in the back analysis are outlined below:

1. Conducting trial and error until conformity with field conditions is attained
2. Sensitivity analysis for individual variables
3. Probabilistic analysis for two correlated variables
4. Advanced probabilistic methods for multiple parameter simultaneous analysis

The back analysis combines field observation and laboratory tests to effectively discover the causes of material failure in engineering (Bakhtiyari et al., 2017).

The limit equilibrium concept also shows the occurrence of slope failure in cases where the driving force exceeds resisting force (Hoek et al., 2002) while a critical condition is observed at two equal dynamisms (Riyadi, 2020). Therefore, a reduction in strength or increment in load leads to collapse due to the stabilization of the heap material to regain equilibrium with an unknown stability factor (FS).

The grain-sized waste dump materials in the study area were analyzed through photo fragmentation evaluation (Elahi and Hosseini, 2017) (Verma, 2017). This was performed using the granule photographs and known scale parameter dimensions for each defined line or section, and the data acquired was analyzed to obtain composite value information for each group (Omah Geo, 2015b).

2. Material and methods

This research was conducted on low-wall heaps which are taller than 150 m with base dip direction of 14°N/165°E and slope of 20°. The in-situ clay rock has an 8 MPa hardness and a pile containing sand-to-boulder material. A circular failure was observed at the top crest to the middle with approximately 70 m at about 300 m tall, 45 m from the crest, and a 10 m drop.

The profiling results showed a material gradation from top to bottom with the grain size increasing gradually towards the base. It is important to note that mine waste dump material composes mainly of sandstone and claystone with mud in several places. The groundwater level was modeled in drain conditions based on visual observation as well as the measurement of the nearest open hole piezometer from the landslide location. Furthermore, a continuously flowing clear water seepage was found at the bottom of the landslide. The initial conditions of the materials obtained through laboratory tests are presented in Table 1.

Table 1
Material properties based on laboratory.

Statistics	Density (g/cc)	C (kPa)	φ (°)	C’ (kPa)	φ' (°)
Average	1.958	66.230	48.744	52.731	21.378
Min. value	1.835	28.634	35.270	13.826	9.330
Max. value	2.116	135.813	67.620	90.902	48.810
Std. deviation	0.123	32.575	8.843	23.307	9.450

The analysis was conducted through a landslide geometry field survey to discover the characteristic patterns and constituent attributes of the materials as the mudslide forms an adjusted circular pattern. Meanwhile, the back analysis was conducted using the limit equilibrium and finite element methods by Slide and Phase2 softwares. The mechanical and physical properties were determined under drain conditions and while the safety factor was less than 1 as shown in Fig. 2.

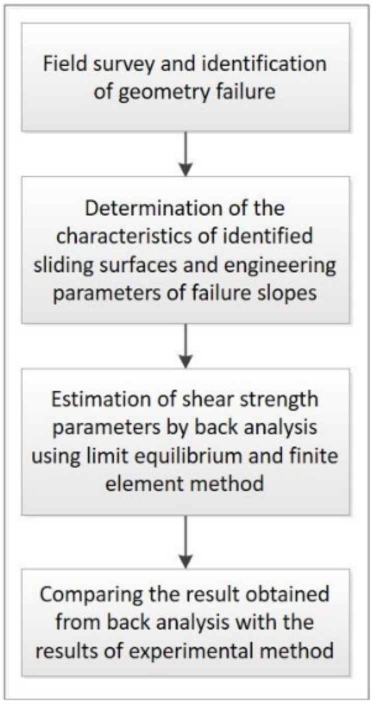


Fig. 2. Back analysis flow diagram.

3. Results and discussion

3.1. Contributing factors

Grain size distribution, changes in groundwater parameters, and slope geometry were the variables discovered to be contributing to the occurrence of a landslide (Omah Geo, 2015a). The heap was sloped above the low wall at the base, while the composite materials were not compact and had several grain sizes. The groundwater in the area was due to rainwater infiltration and the evaluation of the seepage was directly proportional to rainfall intensity because seepage increases even after as little as 24 hours of rainfall. These conditions were also used in landslide probability analysis and modeled at the minimum, maximum, and average levels.

The field investigations showed that there were neither significant disturbances to landslides nor change in the external load. However, blasting was discovered to have occurred at a pit beyond 600 m away, but this was reported by a separate study to be unrelated to the incident (LAPI ITB, 2012; Omah Geo, 2015a). Therefore, it was excluded from the back analysis.

3.2. Grain size & material properties

Grain size was analyzed using a photo fragmentation data group on three trajectories with the landslide location and cross-section shown in Fig. 3 and the results of the analysis in Fig. 4. The largest grain size (> 200 mm) was 18-36% and suspended in a finer matrix (< 200 mm) by medium granules which were 64-82%, while the grain less than 20 mm in diameter was 12-19% (Omah Geo, 2015b).

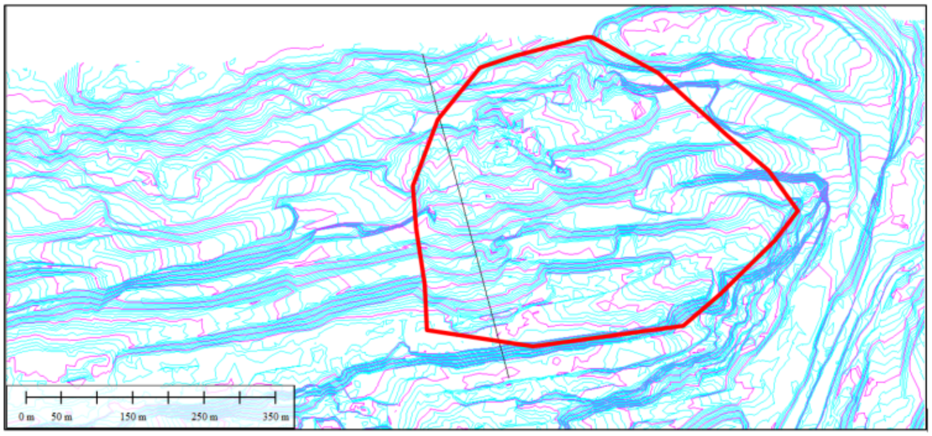


Fig. 3. Location of the slope failure and photo fragmentation line.

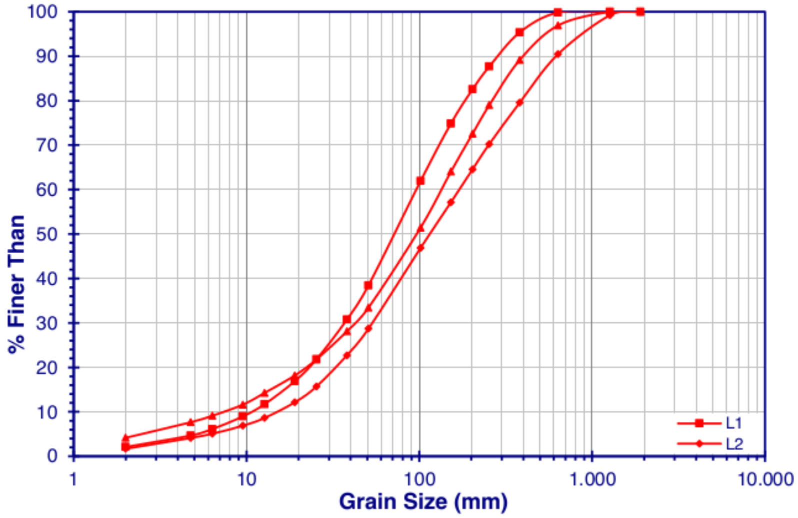


Fig. 4. Composite grain-size distribution based on photo fragmentation.

Subsurface material distribution was evaluated with electric resistivity tomography (ERT) in a bid to identify slope constituents in cross-sections (Indra Karya, 2015), while the groundwater was modeled in the stability analysis and landslide probability prediction with specified minimum and maximum limits. Previous studies have applied the properties of materials to failed slope investigations. The laboratory data was observed to be higher in values than back analysis result and this led to the higher stability factor which means that it was overestimated. This was invalid in cases of failure and this means that further evaluations were required for analytical purposes.

3.3. Back analysis

Landslide stability and the probability of occurrence were ascertained to ensure the applicable regulatory criteria as stated by the Ministry of Energy and Mineral Resources of the Republic of Indonesia (Kementerian ESDM, 2018) were met. These were conducted using the failing mine heap material's initial conditions with the following standards:

a. The smallest stability factor (global minimum) is less than 1
b. Landslide probability is greater than 50%
c. The specified landslide plane always intersects the split point with the detachment point.

This process was used to identify the actual slope conditions with regards to the heap failure and represented the moment a landslide occurred (at any time where the overall slope stability factor (FS) is less than 1). The probability value was estimated to be 50-100% based on heap failure history and this sufficiently depicted the field conditions where the slope was "stable" for a time before the landslide occurred while the slip plane always exceeded the detachment point in order to be suitable for heap failure conditions.

Boundary equilibrium analysis was also conducted on the two-dimensional cross-section of a landslide portion and the results produced a 1.247 higher slope stability value and a 0% landslide probability as shown in Fig. 5.

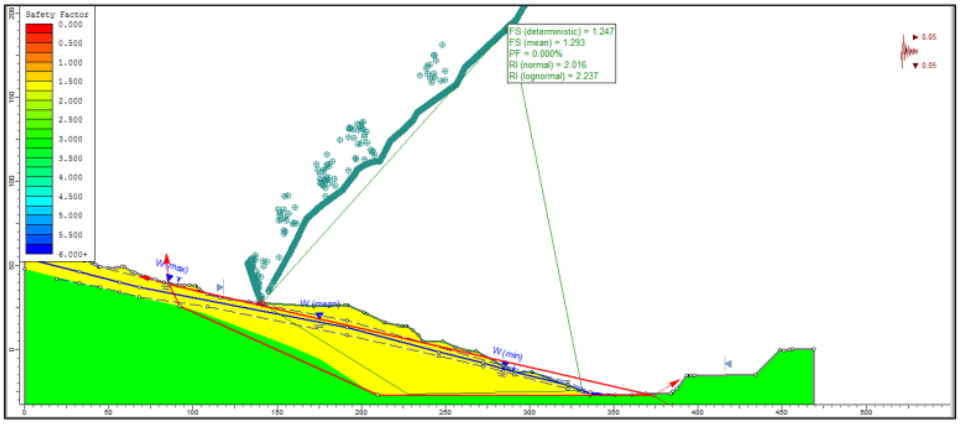


Fig. 5. Slope stability analysis on the failed slope geometry (pre-failure) initial condition using initial laboratory data.

Figs. 6 to 8 showed the results for the initial conditions at SRF 1. The stress distribution at the bottom of the heap was observed to have amplified as the material thickness increased. The red circle at the center of the cross-section in Fig. 6 demonstrated the rise in stress values.

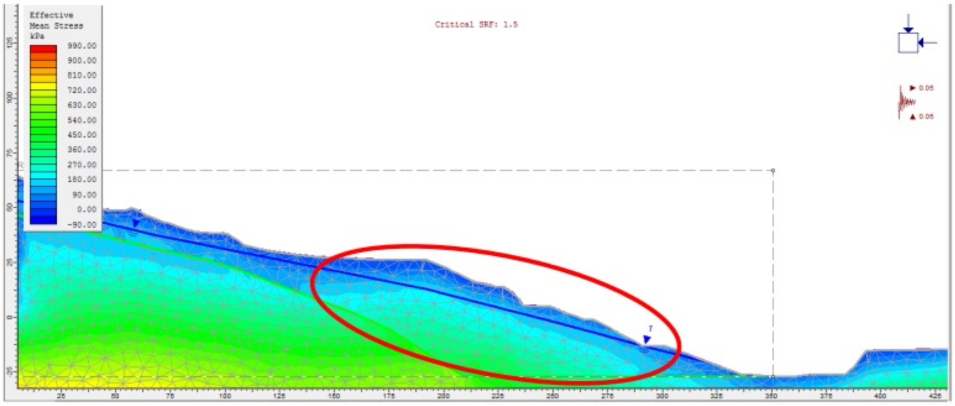


Fig. 6. The result of finite element analysis on initial properties showing the distribution of effective mean stress at SRF 1.0.

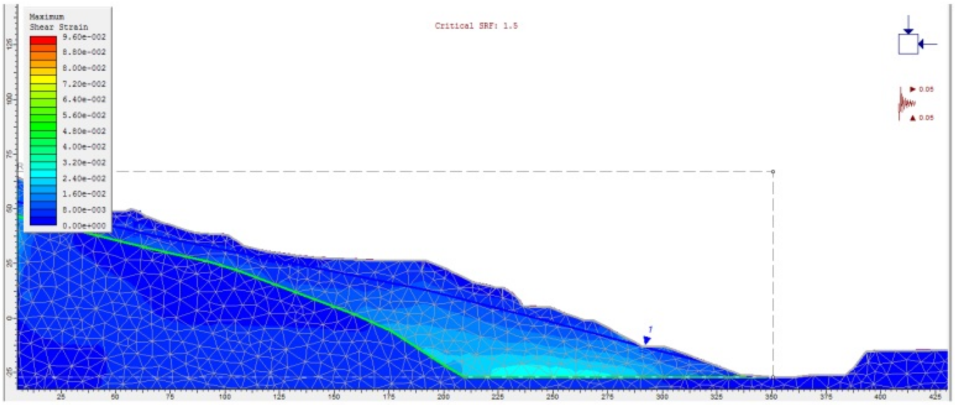


Fig. 7. The result of finite element analysis on initial properties showing the distribution of maximum shear strain at SRF 1.0.

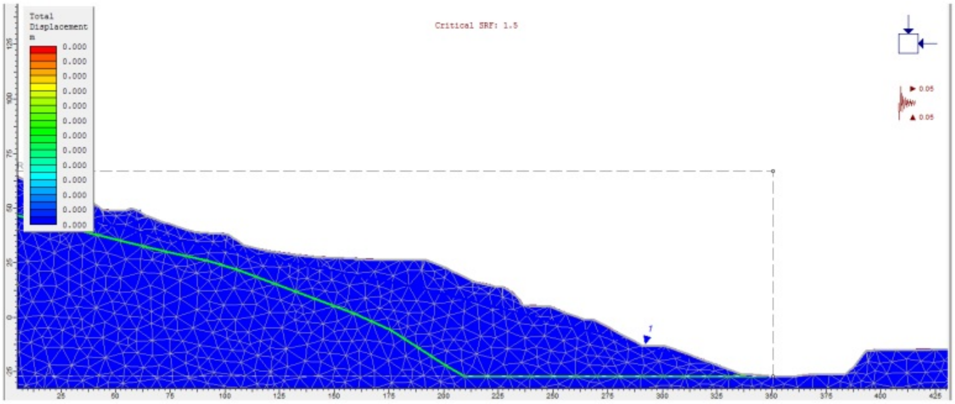


Fig. 8. The result of finite element analysis on initial properties showing the total displacement at SRF 1.0.

The strain and displacement at this state were insignificant due to the strength of the material to maintain slope stability as indicated by a critical SRF value of 1.5. A limited shear strain potential with a <3% score is presented in Fig. 7, while an unidentified displacement is depicted in Fig. 8. These results showed the safe condition of the prior assessment and an overestimated or extremely large stability was suggested by the landslide at this stage.

A more suitable property value for the material was obtained using the back-analysis process and subsequent circumstances were observed to have represented the situation during a landslide based on the slope instability. The limit equilibrium analysis results in Fig. 9 showed the gradient consistency after the back-evaluation process, while the slope stability factor was discovered to be 0.966 with a landslide probability of 58% during the occurrence of the landslide. The groundwater level was included in the probability estimation with the mean represented by the solid blue line while the minimum and maximum are indicated by the dotted blue line.

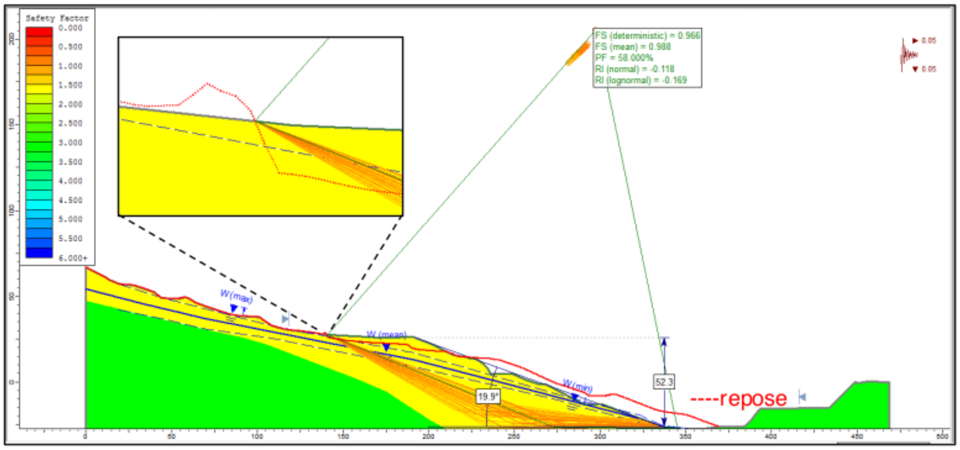
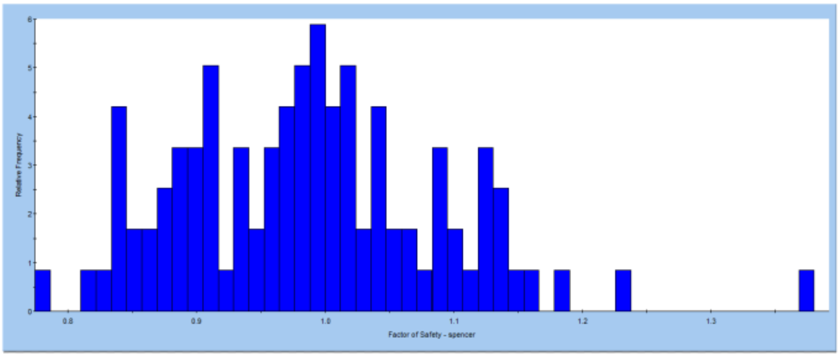


Fig. 9. Slope stability analysis on the failed slope geometry (pre-failure) after back analysis. The insert shows detachment on the upper part of the slope.

Figure 10 shows histogram that represents the stability factors with an average value of 0.988. The majority of the data distribution in the stability factor was found to be between 0.8-1.2, while only a small fraction was beyond this range.



SAMPLED: mean=0.988 s.d.=0.1018 min=0.7854 max=1.38 (PF=58.000% RI=-0.16864, best fit=Lognormal distribution)

Fig. 10. Histogram of the stability factor (FS) in the probability analysis which is used as criteria in back analysis.

The analytical validation was conducted using finite element assessments with the same section shown in Figs. 11 and 12 to evaluate the stress and strain distributions. Meanwhile, the back-analysis criteria in Figs. 11 to 12 used in conjunction with the element evaluation results showed the organization of the effective mean stress, maximum shear strain, and total displacement values at SRF 1.0, and the critical SRF value was consequently obtained at 0.57.

Similarities were, therefore, observed between the effective mean stress distribution at the slope cross-section obtained with the back analysis criteria as shown in Fig. 11 and the assessment performed with the principles of initial conditions as observed in Fig. 12. The stress on the heap material was found to have risen with an increase in thickness.

A substantial shear strain development of approximately 12% in the heap's lower center and bottom is demonstrated in Fig. 12, while a significant rise in the displacement distribution condition at a pattern associated with the shear strain configuration is shown in Fig. 13.

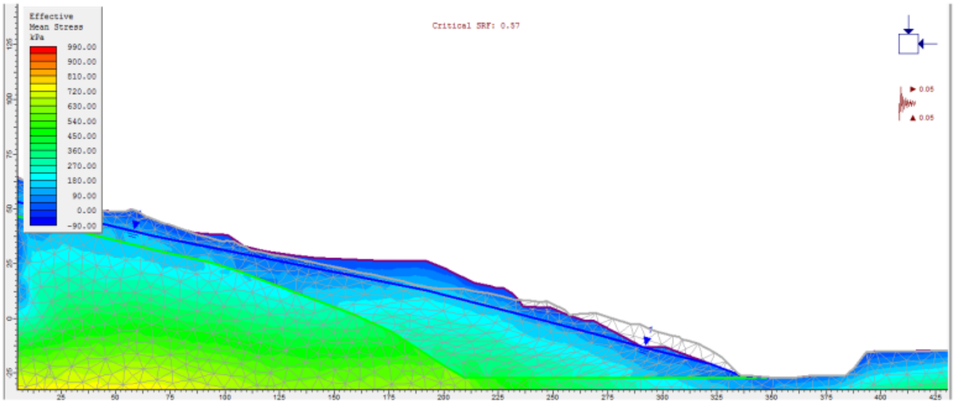


Fig. 11. The result of the finite element on the back-analysis criteria showing the distribution of effective mean stress.

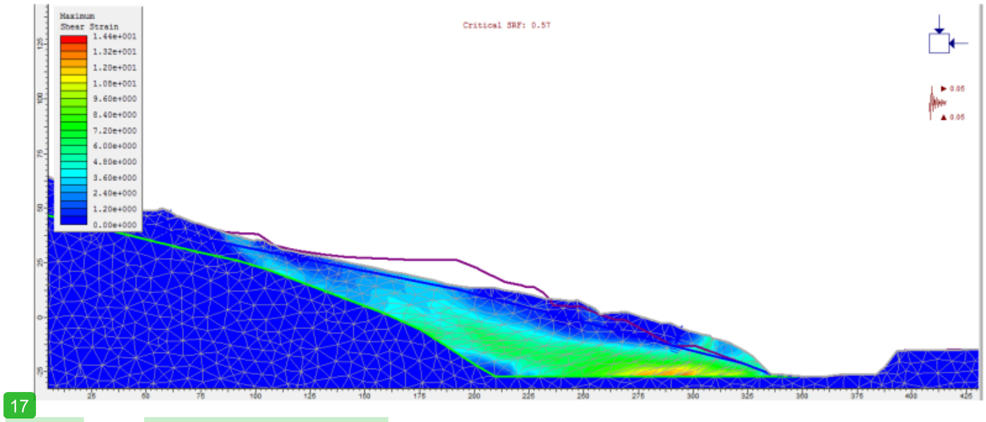


Fig. 12. The result of finite element analysis on back analysis criteria showing the distribution of maximum shear strain.

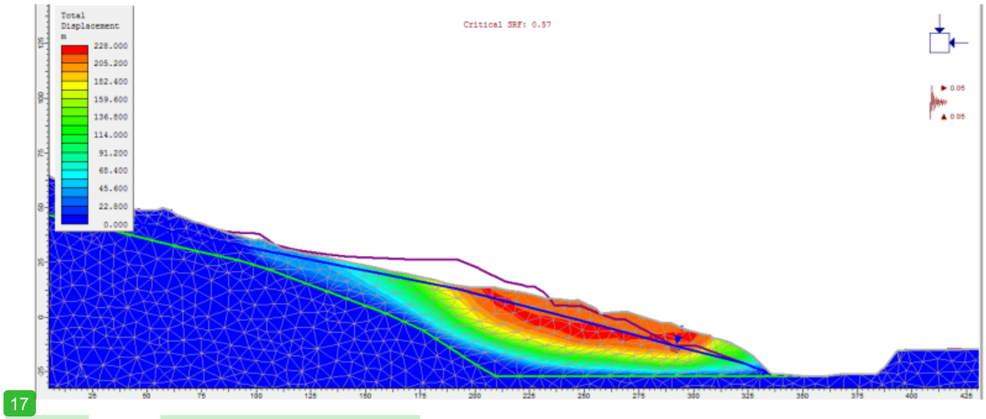


Fig. 13. The result of finite element analysis on back analysis criteria showing the total displacement.

The stability evaluation with the standards generated from the back analysis was considered suitable to represent the actual landslide conditions. This was based on field identification, landslide history, and confirmations from the element analysis conducted to determine the suitability of shear strain distribution pattern, as well as displacement, and slip plane observed in the back-analysis process in relation to the existing conditions.

The back calculation used effective property values to estimate the features of the material proportional to the landslide, while the laboratory data was evaluated by considering landslide causative factors. Moreover, the actual cohesion values were assumed to be inoperative and diminished to 0 at the time of incidence, while the functional parameter was derived from the internal friction angle of the grains/chunks. The variables for the properties of the material obtained through the back analysis are presented in Table 2.

Table 2

Material properties based on the back analysis.

Statistics	Density (g/cc)	C (kPa)	φ (°)	C’ (kPa)	φ' (°)
Average	1.958	33.735	27.352	31.970	25.886
Min. value	1.835	27.459	24.670	18.633	23.300
Max. value	2.116	41.188	31.690	41.188	29.450
Std. deviation	0.123	6.225	2.941	9.599	2.478

3.4. Post failure

The boundary equilibrium was evaluated on post-landslide slope conditions using the back-analysis results as shown in Fig. 14. The overall slope at this stage was found to be steeper than before the landslide and also considered to be a form of natural geometric stabilization.

The stability factor was observed to have increased, while the failure probability decreased significantly at the minimum global stability. This variable increased substantially from 0.966 recorded before landslides to 1.163 post-landslides, while the landslide probability value was roughly 2% after the incidence.

Applicable regulations showed that slopes with high work safety and security risks require a minimum overall stability value of 1.3 and a maximum landslide probability of 5%. Therefore, stabilization remains a requirement for the post-landslide slope geometry to comply with applicable regulatory prerequisites.

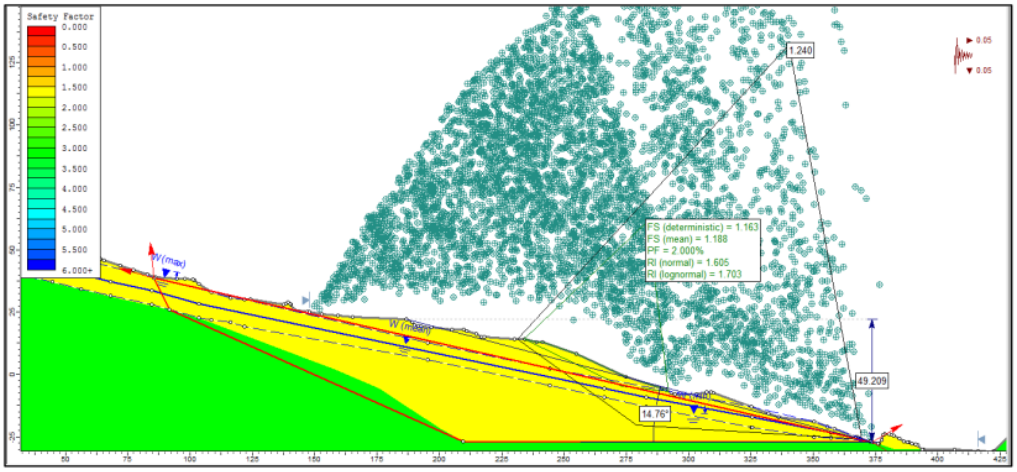


Fig. 14. The analysis of limit equilibrium on the post-failure slope using back analysis criteria.

Further immobility evaluations are recommended in subsequent studies through the application of the results of this back analysis and similar landslides are anticipated with greater trust levels. Observation and identification through a survey or slope mapping are useful in obtaining additional details after stabilization performance. Analytical validations are also applicable with relevant data and information.

4. Conclusion

Slope stability requires maintenance to ensure protection and security, and also to achieve a good mining principle. This sustenance process, therefore, requires the performance of ideal analysis such as the back analysis which represents a vital part of this procedure using representative data and information. The results showed certain variations in the properties of mine waste materials as observed in the values of cohesion and friction angle which changed from 66.230 kPa and 48.774° to 33.735 kPa and 27.352° respectively. This means that there was a reduction in the values of the cohesion and internal friction angle in the back analysis compared to those estimated from the laboratory conditions.

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Reference

Bakhtiyari, E., Almasi, A., Cheshomi, A., Hassanpour, J., 2017. Determination of shear strength parameters of rock mass using back analysis methods and comparison of results with empirical methods. EJERS. 2, 35-42. https://doi.org/10.24018/ejers.2017.2.11.518.

Barritt, R., Scott, P., Taylor, I., 2016. Managing the waste rock storage design — can we build a waste rock dump that works?, in: Fourie, A.B., Tibbett, M. (Eds.), Proceedings of the

11th International Conference on Mine Closure, Australian Centre for Geomechanics, Perth, 131-140. https://doi.org/10.36487/ACG_rep/1608_07_Barritt.

Elahi, A.T., Hosseini, M., 2017. Analysis of blasted rocks fragmentation using digital image processing (case study: limestone quarry of Abyek Cement Company). Int. J. Geo-Engin. 8, 16. https://doi.org/10.1186/s40703-017-0053-z.

Hoek, E., Carranza-Torres, C., Corkum, B., 2002. Hoek-Brown failure criterion – 2002 edition. Proc. NARMS-TAC Conf., Toronto, 1, 267-273.

Indra Karya, 2015. Studi Geolistrik Resistivitas 2D Disposal Area di Low Wall Pit - KPP PT Amanah Anugerah Adi Mulia. Site Kintap, Kabupaten Tanah Laut, Kalimantan Selatan. PT Indra Karya, Malang.

Kainthola, A., Verma, D., Gupte, S.S., Singh, T.N., 2011. A coal mine dump stability analysis. Geomaterials. 1, 1-13. https://doi.org/10.4236/gm.2011.11001.

Kementerian ESDM, 2018. Pedoman pelaksanaan kaidah teknik pertambangan yang baik, KEPMEN No. 1827 K/30/MEM/2018. Menteri Energi dan Sumber Daya Mineral Republik Indonesia, Jakarta.

LAPI ITB, 2012. Studi Geoteknik PT Kalimantan Prima Persada, Asam-Asam, Kalimantan Selatan. PT LAPI ITB, Bandung.

Linero, S., Palma, C., Apablaza, R., 2007. Geotechnical characterisation of waste material in very high dumps with large scale triaxial testing, in: Potvin, Y. (Ed.), Proceedings of the 2007 International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering. Australian Centre for Geomechanics, Perth, 59-75. https://doi.org/10.36487/ACG_repo/708_2.

Mackenzie, S., de Kever, N., Smedley, E., Gregory, S., 2016. Mine waste characterisation — complexities with assessing the physical properties of rock, in: Fourie, A.B., Tibbett, M. (Eds.), Proceedings of the 11th International Conference on Mine Closure, Australian Centre for Geomechanics, Perth, 677-690. https://doi.org/10.36487/ACG_rep/1608_50_Mackenzie.

Omah Geo, 2015a. Field Investigation Report for Slope Failure Back Analysis on The Disposal Embankment of Pit KPP, PT AAAM. PT AB Omah Geo, Yogyakarta.

Omah Geo, 2015b. Photo Fragmentation Analysis on the Back-Filling Disposal Embankment of PT AAAM. PT AB Omah Geo, Yogyakarta.

Öztürk, C.A., Erçelebi, S., Önsel, I.E., Özkan, M., Zengin, M., Arslan, D., Tuncel, Y., Baz, Z., 2015. Open pit mine waste dump area design based on stability principles, in: Kilic, M.G., Basarus, H., Bilgic, E.T., Onel, O., Karadeniz, M. (Eds.), Proceedings of 24th International Mining Congress and Exhibition of Turkey, Antalya, 570-578.

Rachmad, L., Aryanda, D., Daroji, M., 2020. Back-analysis of in-pit dump slope failure and remediation results at Bara Anugrah Sejahtera open pit coal mine, Indonesia, in: Dight, P.M. (Ed.), Proceedings of the 2020 International Symposium on Slope Stability in Open Pit Mining and Civil Engineering. Australian Centre for Geomechanics, Perth, 1059-1068. https://doi.org/10.36487/ACG_repo/2025_70.

Rahul, Khandelwal, M., Rai, R., Shrivastva, B.K., 2015. Evaluation of dump slope stability of a coal mine using artificial neural network, in: Elsworth, D., Huppert, H., Li, J., Ranjith, P.G., Xie, H. (Eds.), Geomechanics and Geophysics for Geo-Energy and Geo-Resources, 1, 69-77. https://doi.org/10.1007/S40948-015-0009-8.

Riyadi, F.A., 2020. Studi Hidrogeologi untuk Penanggulangan Aliran Air di dalam Material Penyusun Alas Saluran. Faculty of Mineral Engineering, Universitas Pembangunan Nasional "Veteran" Yogyakarta, Yogyakarta.

Sakurai, S., 2017. Back Analysis in Rock Engineering. Kobe University, first ed. CRC Press, London. https://doi.org/10.1201/9781315375168.

Tamara Nestovic, Luan T Nguyen, Miroslav Trajkov, 2014. Identification of parameters in nonlinear geotechnical models using extenden Kalman filter. MATEC Web Conf. 16, 05010. https://doi.org/10.1051/matecconf/20141605010.

Verma, A.K., Deb, D., Mukhopadhyay, S.K., 2017. Stability analysis of a mine waste dump over an existing dump. JMMF. 65, 41-48.

Wesley, G., Mackenzie, S., Campbell, G., 2019. Mine waste characterisation: the benefits of applying practical geological knowledge, in: Fourie, A.B., Tibbett, M. (Eds.), Proceedings of the 13th International Conference on Mine Closure, Australian Centre for Geomechanics, Perth, 275-286. https://doi.org/10.36487/ACG_rep/1915_22_Wesley.

Zovodni, Z.M., Tygesen, J.D., Pereus, S.C., 1984. Open pit mine rock dump geotechnical evaluation, in: Proceedings of 1st International Conferences on Case Histories Geotechnical Engineering, Missouri University of Science and Technology, Chicago, 1565-1569.

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