DISPOSAL SLOPE DESIGN BASED ON LOW-PLASTICITY ROCK'S SHEAR STRENGTH IN COAL MINING ACTIVITIES IN SAMARINDA, EAST KALIMANTAN

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ABSTRACT

Slope stability is the primary factor in designing a stable slope. The strength of the disposal slope relies on the characteristic of the dump materials. The rock shear strength denotes rock ability to withstand the burden, both constant and dynamic burden. The weakest material used as a reference in designing the disposal slope is siltstone in Pulaubalang formation (location-04). The safety value in Location 04 and 02 tend to drop quickly as the inclination increase, while the safety in location 01 and 03 tend to drop slowly. This indicates that rocks with a lower plasticity index tend to be stronger in steeper slope conditions. The slope geometry was designed to be 10, 15, 20, and 25 meters high with a slope angle of 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55°, and 60°. The slope geometry is considered stable and safe. However, this study suggests that the most effective slope design is the slope with 25 meters high, overall slope of 25,3°; the single slope of 35°; berm width 4,66 meters, bench height of 5 meters, with the safety factor value of 4.30 (SF= 4.30).

Keyword: Rock Characteristic, Disposal, Slope Stability, Slope Design

I. INTRODUCTION

Open-pit is one of the coal mining systems where all mining activities are performed relatively near the earth's surface. This mining system is profitable only if the coal layer is near the surface *(World Coal Institute, 2021)*. The surface coal mining method typically consists of three activities: overburden removal, coal getting, and reclamation *(Schissler, A. P., 2004)*. The removal and disposal of the covering layers may be affected by geological, geotechnical, and environmental factors. These activities should be carefully planned due to their significant effect on the location surface and rehabilitation *(Oggeri, C. et al., 2018; Allsman PT, Yopes PF, 1973)*. Overburden dumping is a continuous process during the mining process that requires several considerations in designing and selecting the dumping location *(W A Hustrulid et al., 2014)*. *It* is important as inappropriate overburden dumping, i.e., incompliant to the standard operation, can cause unstable slope and landslides *(Behera PK, at al., 2016)*. Therefore, it is necessary to perform a simulation based on the physical, mechanic, and plasticity properties during the disposal slope design process in order to obtain optimum safety value by referring to the weakest material. According to *Nasution, A., (2019),* higher soil plasticity, i.e., wider water content range in the plastic area, tends to be weaker and have higher shrink-swell, causing unstable slope.

II METHODOLOGY

2.1 Time and Location

The present study was conducted in March to August 2021 in several coal mining companies in Samarinda, East Kalimantan:

a. Location-01 : CV. Tampaure Jaya Mandiri Coal with Balikpanan formation dominated by claystone.
b. Location-02 : PT. Insani Bara Perkasa with Pulaubalang formation dominated by claystone.
c. Location-03 : CV. Busur Abadi with Pulaubalang formation consisting of siltstone.
d. Location-04 : CV. Piawai Alam Bumi Perkasa with Balikpapan formation dominated by siltstone. Location coordinate (Table 1 and Figure 1).

These formations are located in Kutai Basin, one of the tertiary basins in Kalimantan, and have different characteristics *(Moss, S. J., et al., 1997)* that vary from one location to another *(Adebayo, B. and Adetula, B., 2013)*.

Table 1 Research locations and sampling points

No	Location	x	y
1	CV. Tampaure Jaya Mandiri Coal	507047	9937827
2	PT. Insani Bara Perkasa	510645	9948198
3	CV. Busur Abadi	514674	9948635
4	CV. Piawai Alam Bumi Perkasa	518282	9951374

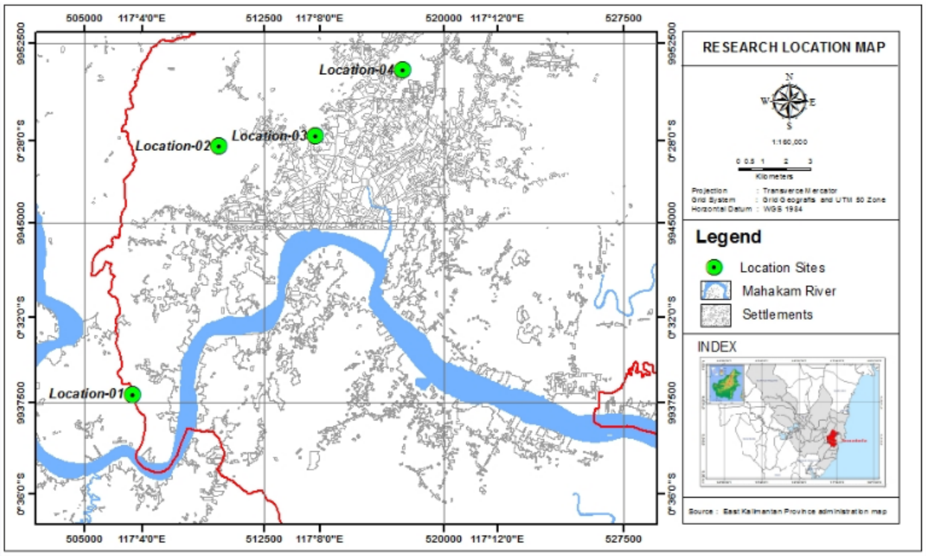


Figure 1. Research site map

2.2 Physical Property Test

Szlavin, J. (1974) argues that a test is required to measure rock properties. A physical property test is carried out to determine values affecting the rock strength, including natural density. Dry density, saturated density, apparent specific gravity, true specific gravity, specific gravity, natural water content, saturated water content, saturation level, porosity, and void ratio. Rock density is a rock's physical property that may substantially change due to different mineralogy and porosity content *(Robert S. Carmichael, 2017)*. The density of poreless sedimentary rock is determined by its mineral composition *(Schön, J. H., 2015)*. The physical property test includes (A) Sample's normal weight (Wn), (b) Saturated Sample Weight (Ww) (c) Saturated *Sample* weight in water (Ws) (d) dry weight (Wo) with temperature ≥ 110° C for 24 hours in an oven (Figure 2)

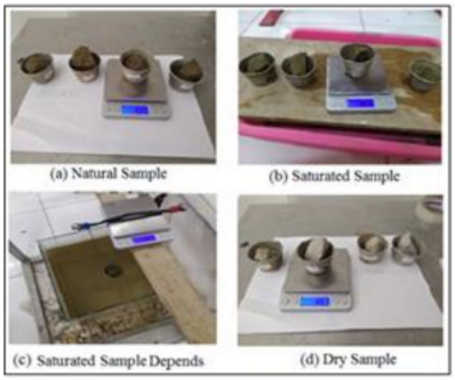


Figure 2. Physical Properties Test

2.2 Atterberg Limit Test

ASTM D 4318-95b is a standard test method to determine the Atterberg limit, namely liquid limit, plastic limit, and plasticity index *(Anthony J. Megel et al., 2006)*. This method is usually used for engineering and geological application *(Knadel, M. et al.,2021)*

a. Liquid Limit Test

Liquid limit describes soil water content between liquid and plastic conditions, determined using the Casagrande test *(E.Díaz et al., 2021; ASTM, 2017)*. Soil liquid limit may decrease due to sampling process and drying process in 60 ° C to 110 °C *(Huvaj, N., & Uyeturk, E., 2018)*. The liquid limit test is presented in Figure 3.

Figure 3. Liquid Limit Test

b. Plastic Limit Test

The plastic limit test is a numerical method used to analyze slope strength *(Li, Z. et al., 2019)* because the soil plastic limit is associated with the soil density characteristic, which helps assess the natural soil promptly *(Nagaraj, H. B., et al., 2015)*. The plastic limit test is performed by pressing and rolling on the clean glass until 3mm-diameter before cracking, and then weighed and put into the oven for 24 hours *(SNI ICS 93.020/2824. 2011*, Figure 4).

Figure 4 Plastic limit test

2.3 Direct Shear Test

The direct shear test is the most common method to test the shear strength of discontinuity of rock, aiming at measuring the peak and residual direct as the normal stress function on the shear plane and finding out the limit of rock in withstanding the shear of burden *(Sanei, M., at al., 2015)*. During the test process, the rock sample was imposed by a certain normal force (Fn) applied perpendicular to the discontinuous plane and friction (Fs) until the rock cracked. The normal stress in each specimen can be viewed as the quotient result from the normal burden and plane area before shear *(Li, W. et al., 2015)*. Cohesion and internal friction angle were determined using different shear stresses, following Mohr-Coulomb's failure criteria *(Tan, H., Chen, F., Chen, J., & Gao, Y., 2019)*.

Figure 5. Shear Strength Test

RESULT

1. The Rock Physical Properties

The result of physical property test used to analyze the safety of the disposal slope was the density value since density is the most important character for geomechanical analysis *(Yusuf, B., Oloruntobi, O., & Butt, S., 2019)*. It is difficult to accurately determine the density of rock materials because of changing volume, porosity, water content, and permeability *(Crawford, Kacy Mackenzey, 2013)*. The density test of rock for disposal slope in each location is presented in Table 2.

Table 2 Average rock density

Location	Dry Density (gr/cm^3)	Saturated Density (gr/cm^3)
01	0,880	1,267
02	1,573	1,612
03	1,540	1,593
04	1,348	1,511

2. Atterberg Limit Test

Atterberg limit is used to determine how far a material can swell or shrink *(Sivakumar et al., 2009)*. The result of Atterberg limit test is displayed in Table 3 and Figure 6.

Table 3 Atterberg Limit

Lokasi	Batas Cair (%)	Batas Plastis (%)	Indeks Plastisitas (%)
01	35,70	26,98	8,72
02	26,50	14,72	11,78
03	34,01	26,00	8,01
04	42,70	28,78	13,92

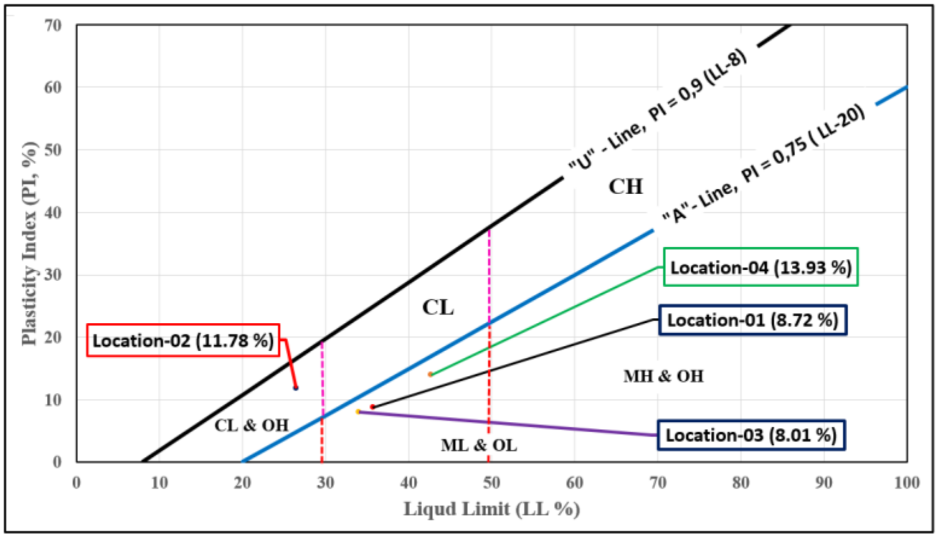
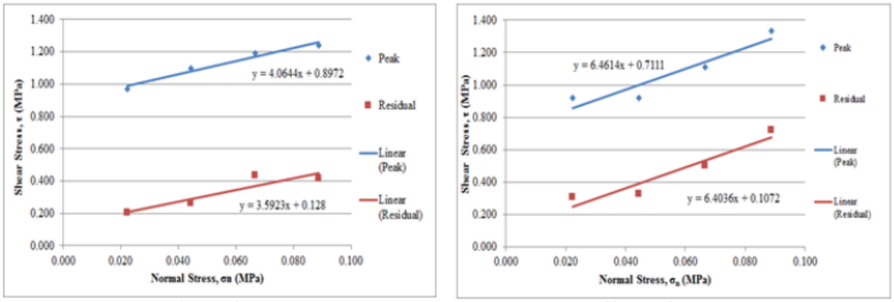


Fig. 6. Plasticity Chart

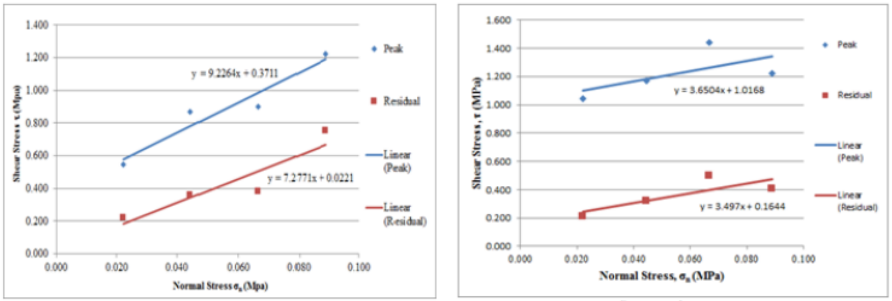
3. *Direct Shear Test*

Rock shear strength refers to the rock ability to withstand the burden, either constant or dynamic burden. The peak shear stress and residual shear strength can be calculated using linear failure envelope that can described using Mohr-Coulomb Criteria*(Anubhav, & Basudhar, P. K., 2010)*. The result is presented in Figure 6.



a) Location-01

b) Location-02



c) Location-03

d) Location-04

Figure 7. Shear Strength Chart

Following the chart above, the shear stress, cohesion, and internal friction angle values are presented in Table 3 and 4.

Table 3. Shear Stress Average

Location	F Shear (kN)		σ_n (MPa)	τ (MPa)	
	Peak	Residual		Peak	Residual
01	1.075	0.313	0.056	1.123	0.328
02	0.988	0.425	0.056	1.070	0.463
03	0.888	0.425	0.056	0.884	0.427
04	1.150	0.338	0.056	1.220	0.359

Table 4. Cohesion and Internal Friction Angle

Location	Curve	Cohesion (MPa)	Internal Friction Angle (°)	UCS (MPa)	UTS (MPa)

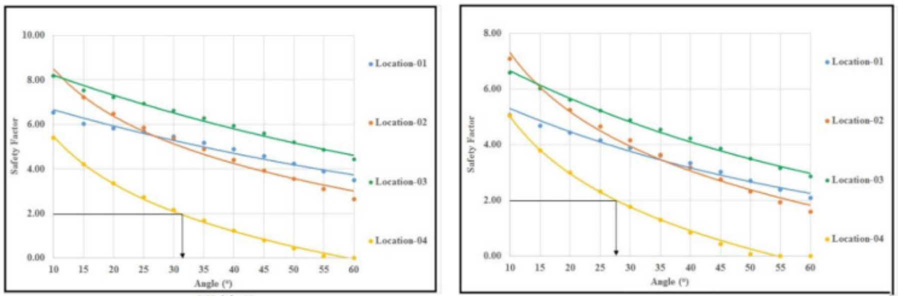
01	Peak	0.8972	76.18	14.80	0.22
	Residual	0.114	65.682	1.87	0.03
02	Peak	0.7111	81.20	18.49	0.11
	Residual	0.0953	71.576	2.76	0.02
03	Peak	0.3711	83.81	13.7358	0.0401
	Residual	0.0196	72.512	0.6463	0.0030
04	Peak	1.0168	74.68	15.12	0.27
	Residual	0.1461	65.329	2.35	0.05

Note : UCS –Unconfined Compressive Strength
UTS- Ultimate Tensile Strength (kekuatan tarik)

DISCUSSION

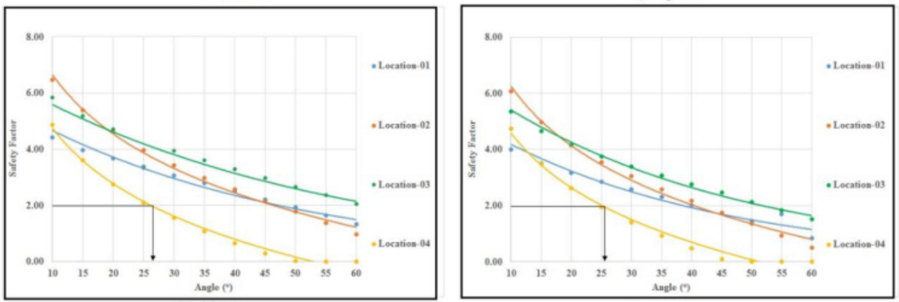
1. Disposal Geometric Planning

The rock properties (physical and mechanical properties) are two important factors determining slope stability *(Willian A. Hustrulid et al., 2009)*. It is difficult to determine the parameter value of slope stability due to the heterogeneity of rock mass. However, it is possible to estimate the general description of the physical and geometric characteristics of slope. Therefore, in measuring slope stability using limit equilibrium method needs to determine the critical form and location that suits the surface *(Ahangar-Asr, A., a 8 al.,2010)*. The slope geometry is designed to be 10, 15, 20, and 25 meters high with 10°, 15°, 20°, 25°, 30°, 35°, 40°, 45°, 50°, 55° and 60° angle. The safety of each height and angle is calculated using an exponential equation. The result is presented in figure 8.



a) Height 10 m

b) Height 15 m



c) Height 20 m

d) Height 25 m

Figure 8. Safety Factor Chart

The chart represents the simulation of slope stability analysis for each location in terms of slope steepness. The simulation shows that each location exhibits different safety levels, depending on the angle. The safety in Locations 04 and 02 tend to drop drastically as the inclination increases, while locations 01 and 03 tend to drop slowly. This indicates that rocks with a lower plasticity index tend to be stronger in a steeper slope.

2. Disposal Geometric Planning

The slope geometry has three important components affecting the slope stability: bench height, overall slope angle, and surface area, the basis to design slope geometry *(Chaulya, S. K., et al., 2016)*. One of the most common methods to analyze slope stability is the simplified Bishop method for its acceptability and plausibility *(Cho, Y.-C., & Song, Y.-S.,2014)*.

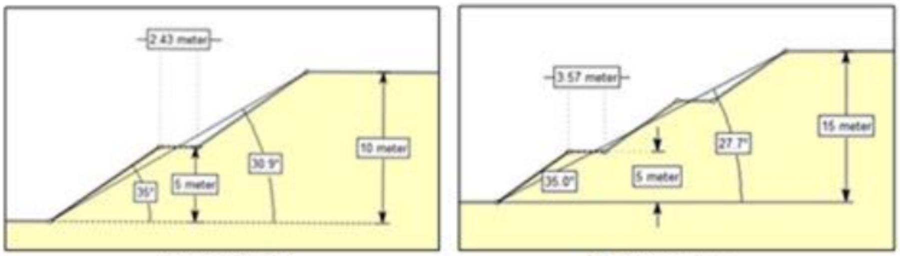
The disposal design was taken based on the weakest rock type by considering several aspects:

a) Less optimal dumping causes the pore to be filled by water easily, resulting in suboptimal water content in dump material.
b) The weak disposal material, i.e., Clayshale.
c) Heavy equipment activity during the reclamation process.
d) Weak disposal ground floor.

Based on the physical property and direct shear tests results, the weakest material for designing disposal slope was siltstone in Balikpapan formation (location-04), as presented in Table 5 and figure 9.

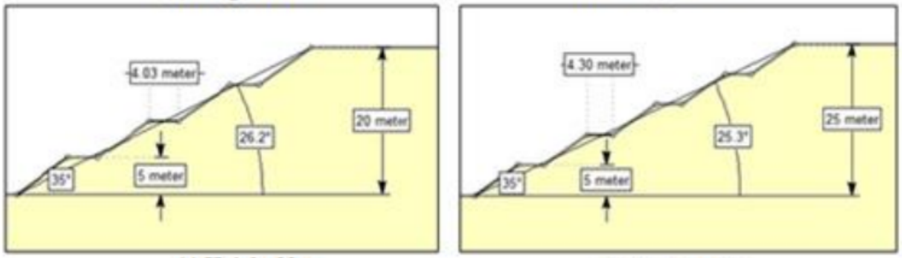
Table 5. Disposal slope geometry design

Slope Height (m)	Overall slope (°)	Bench Height (m)	Single slope (°)	Berm Width (m)
10	30,9	5	35	2,43
15	27,7	5	35	3,57
20	26,2	5	35	4,03
25	25,3	5	35	4,30



(a) Height 10 m

(b) Height 15 m



(c) Height 20 m

(d) Height 25 m

Figure 9. Disposal slope design

As shown in the figure above, the slope geometry (i.e., overall slope angle and slope height) exhibited the most significant effect on the slope stability in the height of 25m and overall slope angle of 25.3°. The slope geometry was considered stable and safe (SF= 4,30) and can withstand the disposal burden.

Conclusion and Recommendation

1. Cohesion and internal friction angle in Atterberg Limits were found to indirectly affect the safety value of the slope design.
2. Rocks with lower plastic index tend to be stronger to withstand the steeper condition.

3. A safe slope design (SF≥2), based on the result of this study, should be 10 -30 high overall, *overall slope* of 24,4° – 30,1°, berm width of 2,43 – 4,66 meters, and bench height of 5 meters.
4. This study suggests that the most effective slope design is the slope with 25 meters high, *overall slope of* 25,3°; *single slope of* 35°; berm *width of* 4,66 meters; bench height of 5 meters with the safety factor value of 4.30.

REFERENCES

1. Adebayo, B. and Adetula, B. (2013), "Evaluation of physical and mechanical properties of rock for drilling condition classification", World Journal of Engineering, Vol. 10 No. 4, pp. 359-366. ISSN:1708-5284. https://doi.org/10.1260/1708-5284.10.4.359.
2. Ahangar-Asr, A., Faramarzi, A. and Javadi, A.A. (2010), "A new approach for prediction of the stability of soil and rock slopes", *Engineering Computations*, Vol. 27 No. 7, pp. 878-893. https://doi.org/10.1108/02644401011073700.
3. Anubhav, & Basudhar, P. K. (2010). Modeling of soil–woven geotextile interface behavior from direct shear test results. Geotextiles and Geomembranes, 28(4), 403–408. https://doi.org/10.1016/j.geotexmem.2009.12.005.
4. Anthony J. Megel, David B. Parker, Rana Mitra, John M. Sweeten, 2006. Assessment of Chemical and Physical Characteristics of Bottom, Cyclone, and Baghouse Ashes from the Combustion of Manure. An ASABE Meeting Presentation. 064043.
5. Arif, Irwandy. 2016. *Geoteknik Tambang*. PT. Gramedia Pustaka Utama. Jakarta.
6. ASTM, 2017. ASTM D4318-17e1, Standard test methods for liquid limit, plastic limit, and plasticity index of soils. ASTM International, 2017, West Conshohocken, PA.
7. ASTM. 1996b. Standard test method for liquid limit, plastic limit, and plasticity index of soils, Standard D 4318-95. West Conshohocken, Pa.: American Society for Testing and Materials.
8. ASTM. 1996c. Standard classification of soils for engineering purposes (Unified Soil Classification System), Standard D 2487-93. West Conshohocken, Pa.: American Society for Testing and Materials.
9. Behera, P. K., Sarkar, K., Singh, A. K., Verma, A. K., & Singh, T. N. (2016). *Dump slope stability analysis – A case study. Journal of the Geological Society of India, 88(6), 725–735*. https://doi.org/10.1007/s12594-016-0540-4.
10. Chaulya, S. K., & Prasad, G. M. (2016). *Slope Failure Mechanism and Monitoring Techniques. Sensing and Monitoring Technologies for Mines and Hazardous Areas,1–86*. https://doi.org/10.1016/b978-0-12-803194-0.00001-5
11. Crawford, Kacy Mackenzey, 2013 "Determination Of Bulk Density Of Rock Core Using Standard Industry Methods", Master's Report, Michigan Technological University. https://doi.org/10.37099/mtu.dc.etds/661.
12. Cho, Y.-C., & Song, Y.-S. (2014). *Deformation measurements and a stability*

analysis of the slope at a coal mine waste dump. Ecological Engineering, 68, 189–199. https://doi.org/10.1016/j.ecoleng.2014.03.005.

13. E.Díaz, J.L.Pastor, Á.Rabat R., Tomás 2021. Machine learning techniques for relating liquid limit obtained by Casagrande cup and fall cone test in low-medium plasticity fine grained soils. Engineering Geology. Vol. 294. p.9. https://doi.org/10.1016/j.enggeo.2021.106381.

14. Huvaj, N., & Uyeturk, E. (2018). *Effects of drying on Atterberg limits of pyroclastic soils of Northern Turkey. Applied Clay Science, 162, 46–56*. https://doi.org/10.1016/j.clay.2018.05.020.

15. Knadel, M., Ur Rehman, H., Pouladi, N., Wollesen de Jonge, L., Moldrup, P., & Arthur, E. (2021). Estimating Atterberg limits of soils from reflectance spectroscopy and pedotransfer functions. Geoderma, 402, 115300. https://doi.org/10.1016/j.geoderma.2021.11530.

16. Li, Z., Hu, Z., Zhang, X., Du, S., Guo, Y., & Wang, J. (2019). *Reliability analysis of a rock slope based on plastic limit analysis theory with multiple failure modes. Computers and Geotechnics, 110, 132–147*. https://doi.org/10.1016/j.compgeo.2019.02.021.

17. Li, W., Bai, J., Cheng, J., Peng, S., & Liu, H. (2015). Determination of coal–rock interface strength by laboratory direct shear tests under constant normal load. International Journal of Rock Mechanics and Mining Sciences, 77, 60–67. https://doi.org/10.1016/j.ijrmms.2015.03.033.

18. Moss, S. J., Chambers, J., Cloke, I., Satria, D., Ali, J. R., Baker, S., … Carter, A. (1997). *New observations on the sedimentary and tectonic evolution of the Tertiary Kutai Basin, East Kalimantan. Geological Society, London, Special Publications, 126(1), 395–416*. https://doi.org/10.1144/gsl.sp.1997.126.01.24.

19. Nagaraj, H. B., Reesha, B., Sravan, M. V., & Suresh, M. R. (2015). *Correlation of compaction characteristics of natural soils with modified plastic limit. Transportation Geotechnics, 2, 65–77*. https://doi.org/10.1016/j.trgeo.2014.09.002.

20. Nasution, A., 2019. Teori Plastisitas (Plasticity Theory). ITB Press. ISBN : 978-602-7861-40-4

21. Oggeri, C., Fenoglio, T. M., Godio, A., & Vinai, R. (2018). *Overburden management in open pits: options and limits in large limestone quarries. International Journal of Mining Science and Technology*. https://doi.org/10.1016/j.ijmst.2018.06.011

22. *Robert S. Carmichael* . 2017. CRC Handbook of Physical Properties of Rocks Volume III Edition1st Edition .Imprint CRC Press. eBook Published 31 August 2017 Pages354. eBook ISBN9780203712030. DOI : https://doi.org/10.1201/9780203712030.

23. Sanei, M., Faramarzi, L., Fahimifar, A., Goli, S., Mehinrad, A., & Rahmati, A. (2015). *Shear strength of discontinuities in sedimentary rock masses based on direct shear tests. International Journal of Rock Mechanics and Mining Sciences,*

75, 119–131. doi: https://doi.org/10.1016/j.ijrmms.2014.11.009.

24. Schön, J. H. (2015). *Density. Physical Properties of Rocks - Fundamentals and Principles of Petrophysics, 109–118*. doi: https://doi.org/10.1016/b978-0-08-100404-3.00004-4.
25. Schissler, A. P. (2004). *Coal Mining, Design and Methods of. Encyclopedia of Energy, 485–494*. doi: https://doi.org/10.1016/b0-12-176480-x/00284-9.
26. SNI ICS 93.020/2824. 2011. Rock Direct Shear Test Guide
27. Sivakumar, V., Glynn, D., Cairns, P., & Black, J. A. (2009). *A new method of measuring plastic limit of fine materials. Géotechnique, 59(10), 813–823*. doi: https://doi.org 10.1680/geot.2009.59.10.813
28. Szlavin, J. (1974). Relationships between some physical properties of rock determined by laboratory tests. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 11(2), 57–66. doi: https://doi.org/10.1016/0148-9062(74)92649-7.
29. Tan, H., Chen, F., Chen, J., & Gao, Y. (2019). *Direct shear tests of shear strength of soils reinforced by geomats and plant roots. Geotextiles and Geomembranes, 103491*. doi: https://doi.org/10.1016/j.geotexmem.2019.1034.
30. Willian A. Hustrulid, Michael K. Carter, Dirk JA, Van Zyl, 2009. Slope Stability in Surface Mining. Society for Mining, Metallurgy, and Explration Inc.8307 Sharffer Farkway.Littleton. Colorado, USA.80127. ISBN : 978-0-87335-295-6..
31. World Coal Institue, Retrivied, 02-11-2021.
32. Yusuf, B., Oloruntobi, O., & Butt, S. (2019). *The formation bulk density prediction for intact and fractured siliciclastic rocks. Geodesy and Geodynamics, 10(6), 446–454*. doi: https://doi.org/10.1016/j.geog.2019.05.005

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