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SOFT ROCK CHARACTERIZATION AND ITS IMPACT TO SLOPE STABILITY AT SESAYAP FIELD COAL MINING, TANA TIDUNG, NORTH KALIMANTAN, INDONESIA

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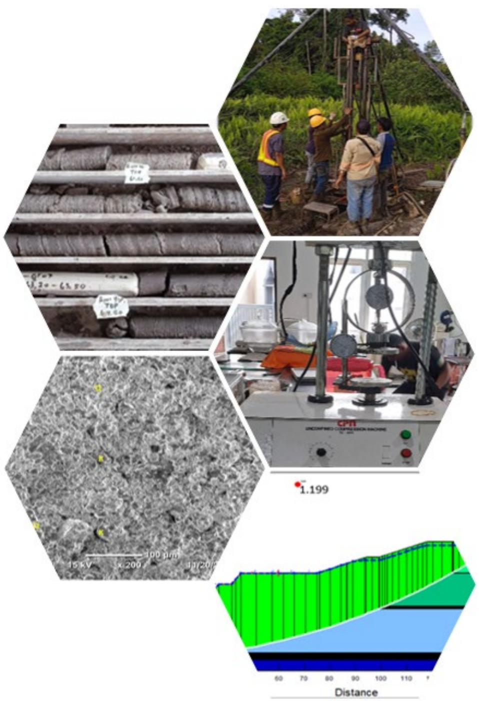


Abstract

Coal mining operation at Sesayap field, Tana Tidung Regency, North Kalimantan Province, Indonesia lies on material soil, sandy clay, claystone and claystone intercalated sandstone and siltstone. The sliding was occurred on soil and loose sandy clay in October 2022, which caused mining infrastructure and financial losses. The objective of this research is to characterize soft rock lithology and its implication to slope stability. The analysis for soft rock material use RQD, SPT, UCS, water content, mineralogy and cohesion. Material characteristic result: RQD average for sandy clay 1.41%, claystone 56.14%, claystone intercalated sandstone 70.80%; water content average for sandy clay 46%, claystone 9%; mineralogy composition for sandy clay quartz 65%, kaolinite 6%, ilit 28%; UCS average data: sandy clay 0.005 Mpa, claystone 0.47 MPa, claystone intercalated sandstone and carbonaceous 1.32 MPa; refer to ISRM 1981 all lithology classified to soft rock. Unit weight for soil 1.53 Kg/m^3, sandy clay 1.47 Kg/m^3, claystone intercalated sandstone-siltstone 1.94 Kg/m^3; cohesion average for soil 6.30 kPa, sandy clay 12.32 kPa, claystone intercalated sandstone 77.14 kPa. Single slope geometry for soil: bench height 5m, slope 20^0; sandy clay bench height 7m, slope 20^0; claystone intercalated sandstone-siltstone bench height 10 m, slope 55^0. Over all slope stability analysis: slope model 1, total height 58m, over all slope 25^0, berm between sandy clay and claystone is 10m, FS static 1.019; slope model 2, total height 58m, over all slope 24^0, berm between sandy clay and claystone is 20m, FS static 1.102; slope model 3, total height 58m, over all slope 22^0, berm between sandy clay and claystone is 30m, FS static 1.194; slope model 4, total height 58m, overall slope 21^0, berm between sandy clay and claystone is 40m, FS static 1.314.

Keywords: Soft rock material, RQD, UCS, XRD-SEM, water content, slope stability

1.0 INTRODUCTION

The characteristic of soft material is fundamental aspect for slope stability evaluation, analysis and assisting safety mining operation guidance. Due to its low strength properties, the mining operation at soft material will face some problems [1]. Improper identification and characterization of soft material, will impact to slope failure.

The mining at Sesayap coal field, North Kalimantan, Indonesia lies on material with low strength characteristic, and the slope was failure in October 2022 impacted to infrastructure loss, coal reserve loss and financial loss. Recently, the characterization of soft rock material is focused on rock strength-UCS parameter. Wang and Liu (2021) mentioned that soft rock material have UCS 0 MPa-25 MPa [4]; ISRM (1981) 0.25 to 25 MPa [27], Terzaghi and Peck (1967) 0,40 MPa, Badu and Gambin (2011) 2-10 MPa [8]; Wang and Liu (2021) 0-25 MPa [4], Almisned and Alqahtani, (2021) 0.97 MPa [7], H. Liu et al 3.49 MPa to 39.01 MPa [12]. Another researcher allows mineralogical composition as the characteristic of soft rock material: Miscevic and Vlastelica (2014) identified quartz marl content: calcite 42%-79%, dolomite 2%-7%, vermiculite 5%-6%, quartz 3%-11%, plagioclase 1%-9%, smectit and ilite 3-12%, chlorite 4-9% [6]; Almisned and Naif (2021) identified sandtone content quartz 91%, hematite 5% and kaolinite 2.9% [7].

Beside the UCS and mineralogy, this research will characterize soft rock material by adding other parameter: RQD, SPT, water content, and cohesion. After got soft material characteristic, then will be continued by analyzing slope stability.

2.0 METHODOLOGY

Soft rock characteristic in this study was conducted by analyzing RQD, SPT, water content, XRD-SEM, UCS and cohesion. RQD, SPT and core sample were acquired by drilling, sample from drilling core was laboratory analyzed to get parameter water content, UCS, cohesion, unit weight, friction angle and mineralogy. Unit weight, cohesion and friction angle finally are used as material parameter for slope stability analysis.

Geotechnical drilling was performed using Jacro 175 machine with full rotary system, core barrel size size 54.7 mm, and vertical penetration direction. Drilling location covered all part of pit mining, including western high wall, northern side wall, and eastern low wall, with total 6 holes, ranging in depth from 30 m to 70 m.

Drilling SPT is conducted to determine dynamic resistance and soil-material sample, refer to SNI 4153-2008 [19] and ASTM D 1586-84 Standard penetration test and split barrel sampling soil. SPT drilling was performed using Jacro 175 machine, split barrel sampler, and other SPT apparatus.

Drilling geotechnical and SPT map location are depicted as Figure 1.

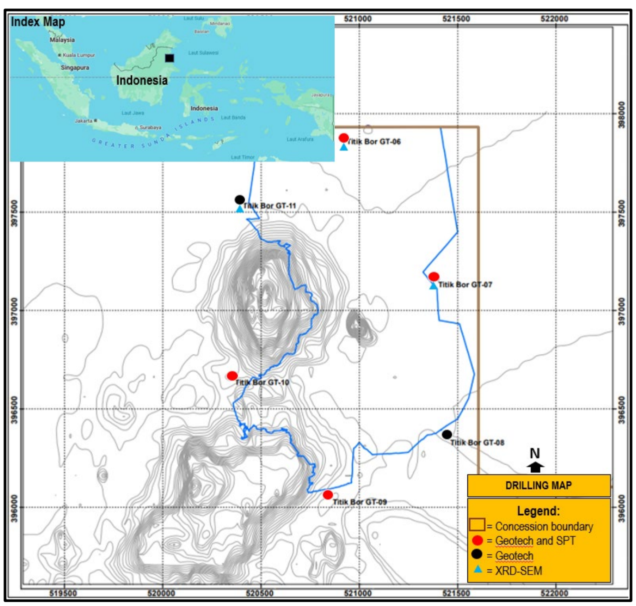


Figure 1-Field data acquisition map for soft rock characterization

Unit weight, cohesion and friction angle was identified for 29 samples, water content 17 samples, mineralogy test 3 samples, and UCS 26 samples which depicted at Table 1 and Figure 2.

Table 1-Summary laboratory testing

TEST	SAMPLE
Unit Weight, cohesion, friction angle	29
Water content	17
XRD-SEM	3
UCS	26

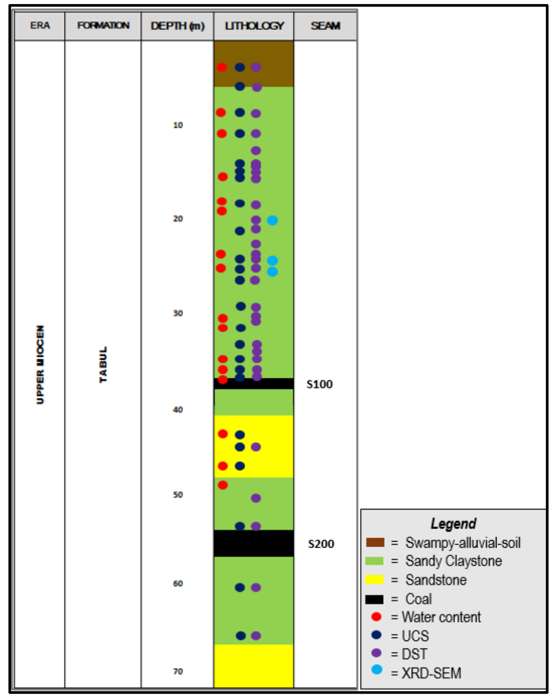


Figure 2-Sampling position for soft rock characterization

Schema flowing diagrammatic for research methodological are depicted as Figure 3.

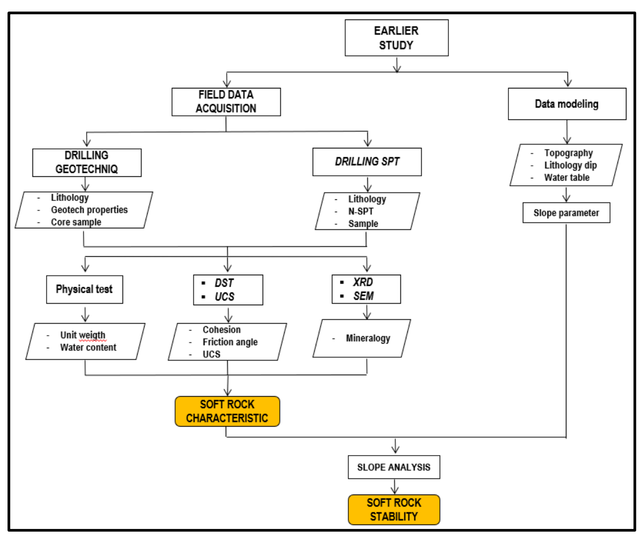


Figure 3-Schema flowing diagram research methodology

3.0 RESULTS AND DISCUSSION

3.1 Geological Setting

Coal mining operation at Sesayap field, Tana Tidung Regency, North Kalimantan Province, Indonesia lies on soil, sandy clay, claystone, and claystone intercalated sandstone-siltstone. Geologically, Sesayap coal field is part of Tarakan Basin, Tarakan Sub Basin [2], coal bearing formation is Tabul Formation of Late Miocene, formation comprises of claystone, mudstone, sandstone, limestone and coal as Figure 4. Alluvial material consists of mud, silt, sand, gravel, coral from coastal, river and swampy sediments [3]. Morphology is weak to moderate *undulating* hills transitioning into flat pain. Lithology consists of alluvial debris, swamp deposit, sandy claystone, siltstone, sandstone and coal, geology structure syncline fold trending northeast-southwest of dip 5^0 as Figure 5.

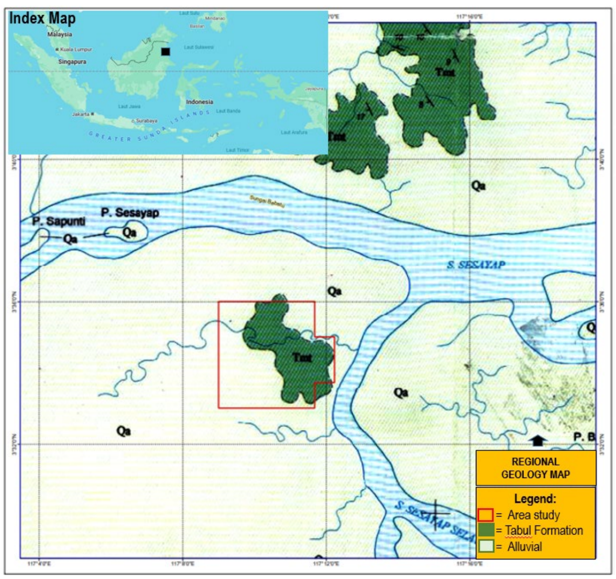


Figure 4-Geology regional map area Sesayap field

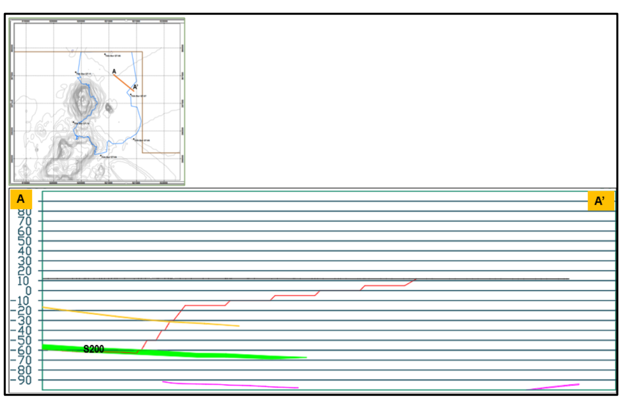


Figure 5-Coal geological modeling at Sesayap Field

3.2 Drilling Core Description And Analysis

Drilling core description is used to identify strength estimation, degree of weathering, texture, discontinues surface, and RQD. Based on core-drilling, lithology at Sesayap field consist of soil, sandy clay, claystone, claystone intercalated siltstone and sandstone. Soil is alluvium material, and sandy clay, claystone intercalated siltstone and sandstone are the part of member Tabul Formation. The detail description for every lithology are:

- Soil, loose alluvial material, brownish to blackish in color, light weight, porous, show remnants of tree branches and twigs, thickness range from 2 m to 5 m.
- Sandy clay as Figure 6, very weak material, very low to low strength, looses, weathered, light to dark in color, clay size grain, contain sandy, laminated texture, high plasticity, thickness range from 15 m to 18 m.
-

Figure 6-Photo core of sandy claystone

- Claystone, claystone intercalated siltstone and sandstone as Figure 7, low to medium strength, light to dark in color, clay size grain, low plasticity, thickness range 10 m to 20 m, discontinues surface bedding plane with dip 5^0.

Figure 7-Photo core of claystone, claystone intercalated with sandstone-siltstone

From the drilling core description, can be summarize that at depth 0 m to ± 20 m soil and sandy clay has the characteristic loose, very low strength, high plasticity, weathered to slight weathered. In this interval, material do not have good grain binding cement due to immature geological process, identify by its low RQD, high water content and low cohesion. Claystone, claystone intercalated sandstone and siltstone at depth ±20 m to ±70 m, show the more compact material, low to medium strength, low plasticity, fair to good grain binding cement due to mature geological process identify by compact and stronger. Base on slope feature in coal mining, soil and lose sandy clay relatively have the higher potential problem for sliding during mining operation rather than material claystone and claystone intercalated siltstone and sandstone in bottom area.

3.3 SPT Analysis

Based on SPT data, the typical material performs the slope mining consist of:

- Soil, black to brownish in color, contain remnants of branches and twigs, very plasticity, thickness ranging from 2m to 4.90 m, N blow 1 to 2.
- Clay, light grey in color, medium to high plasticity, extremely low strength, contain sandy material, thickness 15 m to 20 m, N blow 2 to 30.
- Claystone as bed rock at depth 23 m to 30 m.

SPT data in line with drilling data, material with characteristic very low to low strength and high plasticity was found at interval 0 m to ± 20m, and material with medium to high strength was found at depth ± 20m to ±70 m. The graph of N-SPT values is shown in figure 8 as below.

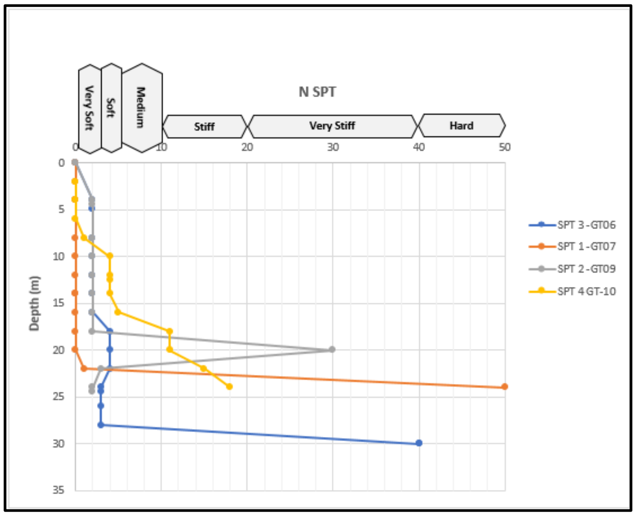


Figure 8-NSPT graphic at Sesayap fields

Refer to figure graphic SPT above, we can conclude that material bed rock was found at depth 23 m to 30 m. This interpretation in line with drilling data lithology claystone with intercalated sandstone and siltstone which more strength, compact and dense, was found start at depth ± 20 m.

3.4 RQD Analysis

Rock quality designation means percentage of intact rock from every piece of core sample which length more than 10 cm in the total length of core, Deere, 1972 [9]. RQD is one of parameter for rock mass classification to support slope stability evaluation [18]. The discontinuity surface in core represents bedding-laminated sediment, fracture, joint and shear surface. Higher the RQD, better the quality of rock mass and smaller the RQD, lower the quality of rock.

Soil has RQD minimum 0%, maximum 9%, average 1.36%, very poor-quality rock. Sandy clay has minimum 0%, maximum 19%, average 1.41%, very poor-quality rock. Claystone have minimum 20%, maximum 100%, average 56.14%, carbonaceous claystone has the minimum 20%, maximum 100%, average 78.59%, claystone intercalated sandstone-siltstone have the minimum 53%, maximum 93%, average 70.80%, sandstone-siltstone have the minimum 18%, maximum 100%, average 74.62% and claystone as under burden have the minimum 33%, maximum 100%, average 78.03%, fair to good quality rock. The statistic of RQD data from Sesayap Coal Field is shown in Table 2 and Figure 9.

Table 2-Statistical RQD data

Lithology	RQD %			
	n	Min	Max	Avg
Soil mix peat	11	0	9	1.36
Loose sandy claystone	29	0	19	1.41
Claystone	29	20	100	56.14
Carbonaceous claystone	27	20	100	78.59
Claystone intercalated sandstone	10	53	93	70.80
Sandstone-siltstone	15	18	100	74.62
Claystone-2	31	33	100	78.03
Coal	5	53	100	85.20

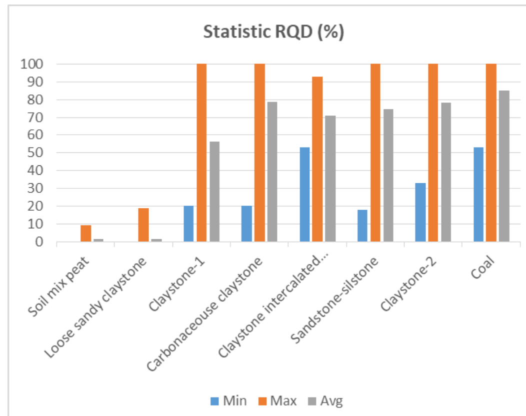


Figure 9-Graphic statistical RQD data at Sesayap coal field

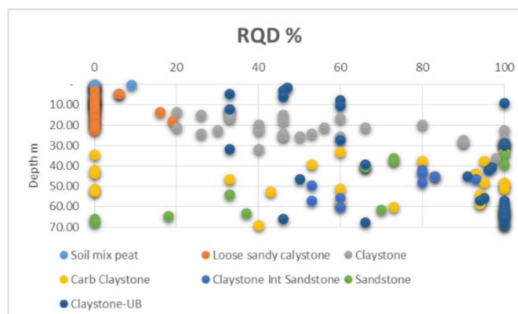


Figure 10-Graphic RQD distribution at Sesayap coal field

From figure 10, soil and sandy clay with total thickness ± 20 m have the lowest RQD mean the rock mass is very poor quality, which is shown by loose structure, and imply to increase water content within pore. The lithology was slide in area study.

The lower stratigraphic position is claystone with interval depth ranging from 20 m to 30 m, average RQD 56.14%, carbonaceous claystone, claystone intercalated sandstone-siltstone, sandstone and show the RQD 70-85%, fair to good. The lithology in this interval shown by more compact structure and more degree of strength.

3.5 Physical Properties

3.5.1 Moisture Content

Moisture content describes the amount of water contained within the pore of material. Pore is void between grains formed by diagenesis process or fractures caused by geological structures. Water content reduces the cohesion between mineral grain and finally decreases rock strength. Summary statistical and graphic water content at Sesayap coal field are depicted in Table 3 and Figure 11.

Table 3-Summary statistical data moisture content at Sesayap coal field

Lithology	n	Moisture Content (%)		
		Min	Max	Avg
Loose sandy claystone	5	34.24	86.08	46.07
Claystone	7	7.79	11.09	9.16
Siltstone-sandstone	3	7.91	12.53	10.60
Carbonaceous claystone	2	6.19	6.31	6.25

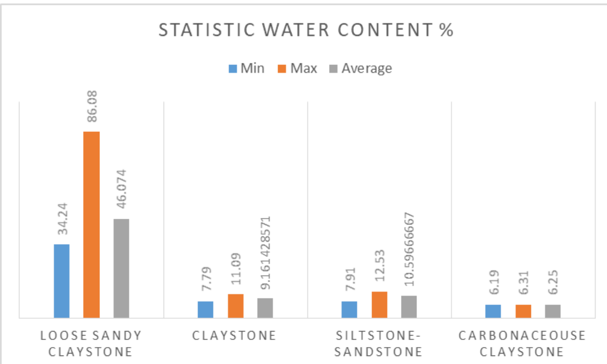


Figure 11-Water content graph statistic at Sesayap field

Base on statistical data, we can see that the sandy clay has the average minimum 34%, maximum 86% and average 46%, claystone has the minimum 7%, maximum 11%, average 9%, siltstone-sandstone and carbonaceous claystone have the minimum 6%, maximum 12% and average 10%. The graphic of water content at Sesayap field is depicted as Figure 12 below.

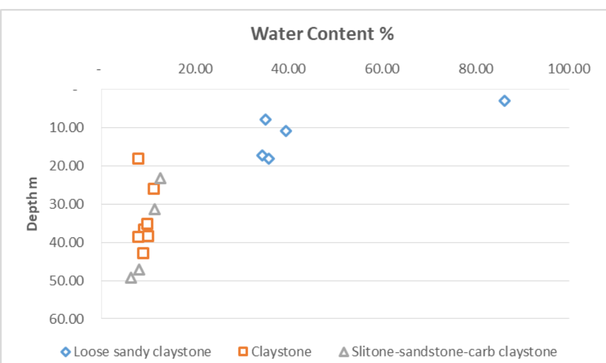


Figure 12-Graphic water content at Sesayap field

From the graph, we can see that at depth 0 m to 20 m, soil and sandy clay have the water content 34% to 88%. The higher water content in this material relates with its loose structure, whereas the degree of bounding between mineral grains are very low, and cause the pore is filled by water, and finally decrease the cohesion. Lithology claystone, carbonaceous claystone, siltstone and sandstone at interval depth 21 m to 50 m have the water content around 7% to 12%. The low water content in this lithology relates with its physical characteristic with more compact material whereas bounding between mineral grains are close and well cemented, and cause the pore is small, and increase the cohesion and material strength.

3.5.2 Unit Weight

Unit weight represents the ratio of the rock mass weight to its volume, expressed in Kg/m^3. Unit weight was influenced by the weight of each mineral composing the material per volume. he summary statistical data unit weight and graph are shown in Table 4 and Figure 13.

Table 4-Summary statistical data unit weight at Sesayap field

Lithology	n	Unit Weight (Kg/m^3)		
		Min	Max	Avg
Soil	1	1.53	1.53	1.53
Loose sandy claystone	10	1.14	1.91	1.47
Claystone	8	1.51	2.55	1.94
Claystone intercalated Sandstone	6	1.56	2.20	1.83

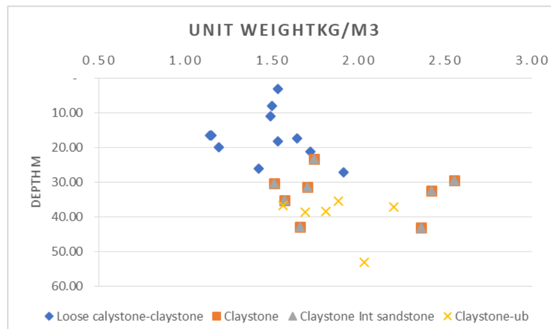


Figure 13-Graphic unit weight at Sesayap field

Data unit weight, cohesion and friction angle then will be use as parameter in slope stability analysis as Mohr Coulomb criterion failure. For this objective, unit weight from every lithology then grouped by zone stratigraphy with the summary as below soil is 1.53 Kg/m^3, sandy clay 1.47 Kg/m, claystone intercalated sandstone and siltstone 1.94 Kg/m^3, claystone contain carbonaceous 1.83 Kg/m^3, claystone as under burden is 2.03 Kg/m^3.

3.6 Mineralogy

3.6.1 X-Ray Diffraction XRD

X-Ray Diffraction has been analyzed in sandy clay samples with result: quartz (SiO_2) 62.3%-69%, kaolinite ($Al_2Si_2O_5(OH)_4$2.9%-6.7%, and ilit $(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)$ 24.4%-31.3% as shown at Table 5 below:

Table 5-Summary XRD test result at Sesayap field

No	Sample	Quartz % SiO_2	Kaolinite % $Al_2Si_2O_5(OH)_4$	Ilite % $(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)$
1	SPL-2-GT-06	62.3	9	28.7
2	SPL-2-GT-07	65.8	2.9	31.3
3	SPL-3-GT-11	69	6.7	24.4

The graphic XRD show the mineralogy composition are shown at Figure 14, 15 and 16 as below.

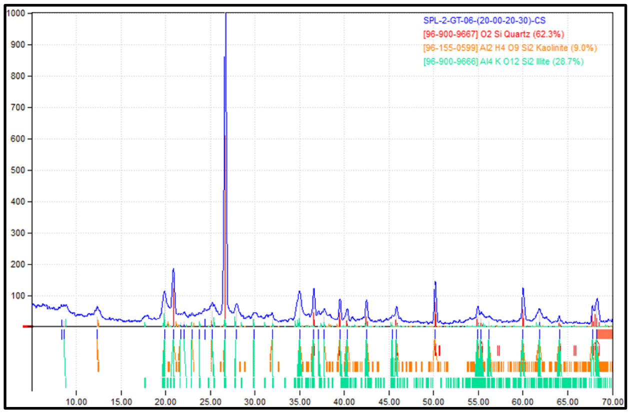


Figure 14-Graph XRD test at sandy clay sample-2-GT-06

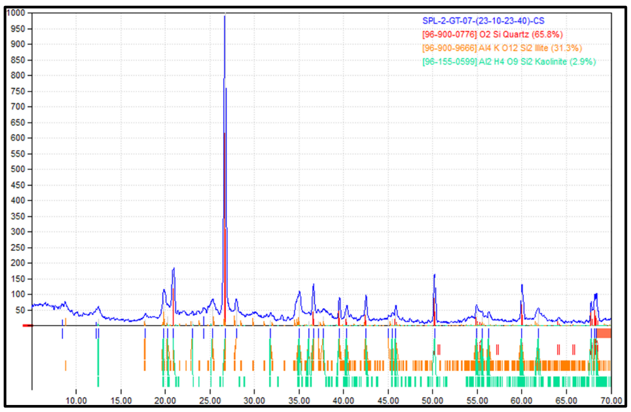


Figure 15- Graph XRD test at sandy clay sample-2-GT-07

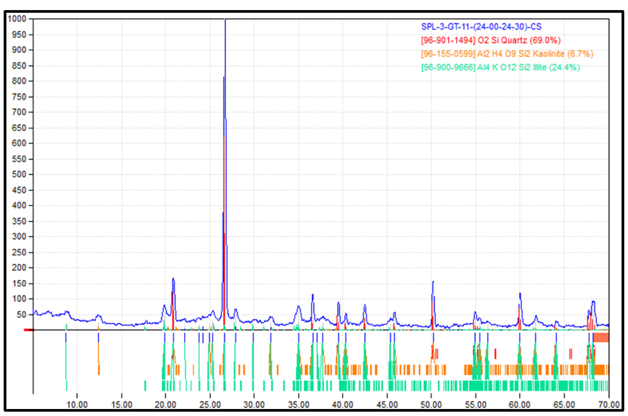


Figure 16- Graph XRD test at sandy clay sample-3-GT-11

3.6.2 Scanning Electron Microscopy-SEM

Scanning electron microscopy will analyze mineral with high magnification, allowing detail visualization on the shape and size mineral clay. SEM analysis was performed at sample sandy clay and shown as Figure 17, Figure 18 and Figure 19.

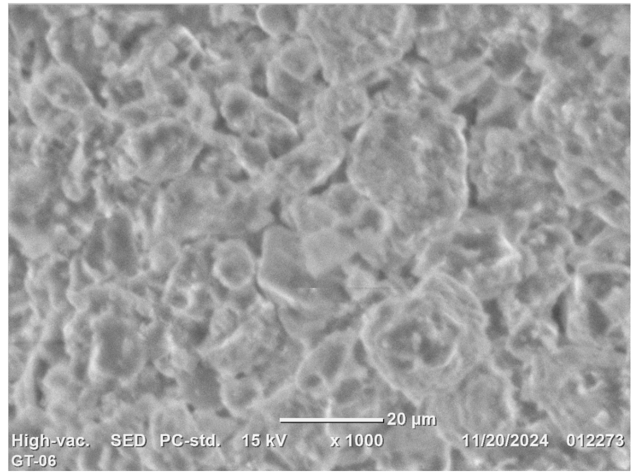


Figure 17-SEM analysis at sample SPL-02-GT-06

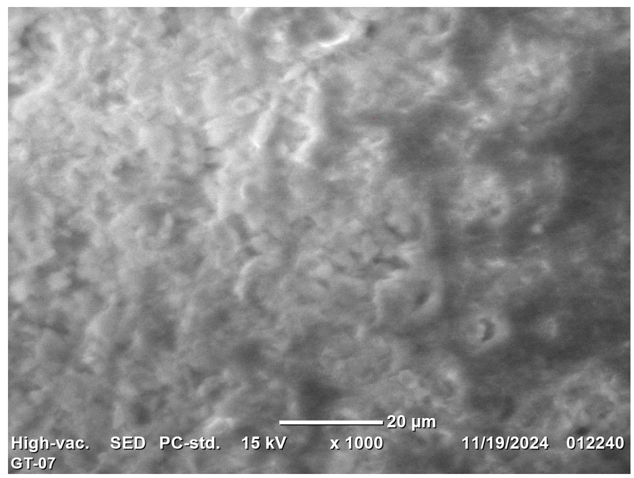


Figure 18- SEM analysis at sample SPL-02-GT-07

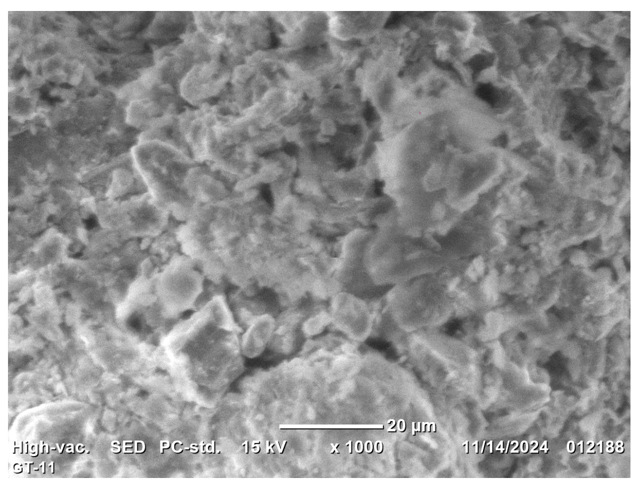


Figure 19-SEM analysis at sample SPL-02-GT-11

Figure 17, 18, and 19 show that the quartz is dominant composition, and follow by ilite and kaolinite. Kaolinite and ilite as clay mineral are the absorber and consume the water due to extra electric charge formed on their surface mineral. Clay mineral beneath the rock be negatively charged, and then the large absorption energy for water was induced [27, 30]. This characteristic finally accumulates the water in the material will be saturated, and cause cohesion and strength decrease and initially to fail.

Refer to soft rock classification proposed by He, (2014) [27], so the soft rock material in Sesayap coal field categorized as Expansive soft rock which mean the material will face the sliding when applied external force and also the material will expanse and swell when water surface infiltrate to the rock. Base on field observation, actual slope condition, and this mineralogy XRD-SEM testing, can be conclude that one factor as trigger for slope wall mining sliding in October 2022 is due to its kaolinite and illite composition in clay stone. Refer to Li et.al (2024) [28], so the lithology soil and sandy clay are as internal factor for sliding.

3.7 Mechanical properties

3.7.1 Unconfined Compression Stress

Unconfined compressive strength (UCS) measures the one-directional stress with continuously applied to a rock's surface till fail when the applied force exceeds its strength.

The statistical data UCS at Sesayap coal field are depicted in Table 6 and Figure 20.

Table 6-Statistical UCS data at Sesayap field

Lithology	n	UCS (Mpa)		
		Min	Max	Avg
Claystone	19	0.00	3.43	0.47
Sandstone	3	0.00	3.36	1.23
Carb Claystone	3	0.14	3.21	1.32

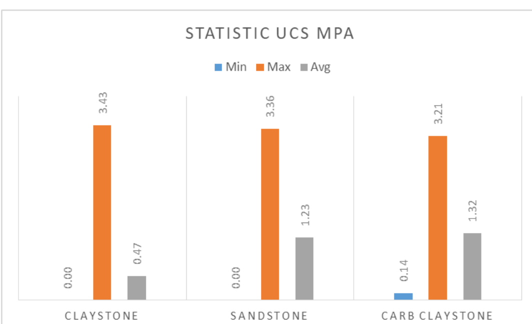


Figure 20-Graphical statistical UCS

Claystone include loose sandy clay has the UCS minimum 0.00 MPa, maximum 3.43 MPa and average 0.47 MPa. Sandstone have the minimum UCS 0.00 MPa, maximum 3.36 MPA, average 1.23 MPa. Carbonaceous claystone has the minimum UCS 0.14 MPa, maximum 3.21 MPa and average 1.32 MPa. Relate to depth interval position, the material at depth 0 m to 20 m have the UCS with range from 0.00 MPa to 0.12 MPa, and at interval 19 m to 70 m have the UCS with range from 0.14 MPa to 3.46 MPa. Base on UCS value from all the sample, and refer to ISRM rock strength classification [27], can be conclude that all lithology in Sesayap Field are classified as Soft Rock. The graphic of UCS data at Sesayap coal filed is depicted as Figure 21 below.

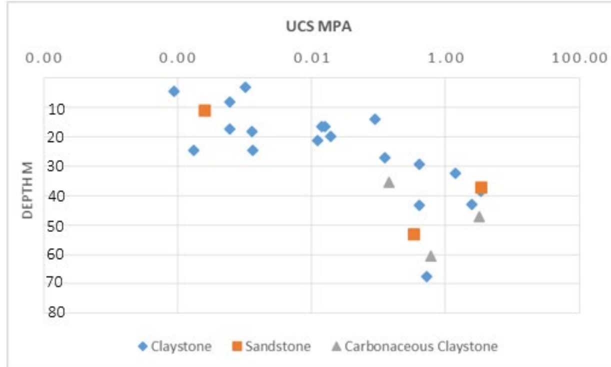


Figure 21-Graphic UCS at Sesayap coal field

The interrelationship between RQD, water content and UCS are state below:

- At interval 0 m to ±20 m, soil and sandy clay have the RQD 0% to 19%, imply the low grain binding and pore will be filled by water with range 34% to 86%, very low strength from 0.00 MPa to 0.12 MPa, low cohesion and material have the high potential to slide.
- At interval ±20 m to ±70 m, claystone, claystone intercalated siltstone and sandstone, carbonaceous claystone have the RQD 20%-100%, fair grain binding, water content 6% to 12%, and the strength range from 0.12 MPa to 3.40 MPa.

3.8 Cohesion and Friction Angle

Cohesion represents the degree of bonding strength between particle-grain mineral in rock structure. A higher cohesion implies stronger rock mass. In slope stability, cohesion represent the resistance require to maintain slope stability during land slide. Internal friction angle represents the internal force during failure, higher the friction angle, the more stable the slope become. The result cohesion test is shown at Table 7 and Figure 22.

Table 7-Statistic cohesion-friction angle.

Lithology	n	Cohession KN			Friction angle (0)		
		Min	Max	Avg	Min	Max	Avg
Soil	2.00	2.50	10.10	6.30	16.10	27.81	21.96
Loose sandy claystone	13.00	0.80	31.00	12.32	3.20	35.91	21.57
Claystone	4.00	62.00	133.00	91.00	17.11	26.83	24.47
Claystone int sandstone	7.00	20.00	169.00	77.14	7.42	34.42	21.46
Claystone-UB	2.00	64.00	120.00	92.00	23.12	34.20	28.66

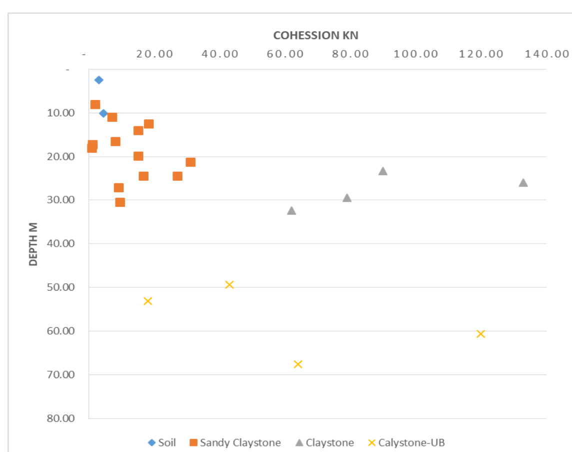


Figure 22-Graph cohesion at Sesayap coal field

From the graphic we can see that soil and sandy clay in depth 0 m to ± 20 m has the low cohesion, low UCS, low RQD and high water content. The lithology claystone, claystone intercalated sandstone and claystone as under burden with depth deeper than 30 m has the relatively higher cohesion and related with compact structure, relatively high RQD, low water content, and higher UCS.

Base on this study, the characteristic soft lithology are RQD 20% to 0%-100%, N-SPT 0 to 50, UCS 0.00 MPa to 3.46 MPa, water content 9% to 86%, mineralogy quartz 62.3%-69%, kaolinite 2.9%-6.7%, and ilit 24.4%-31.3%, cohesion 6.3 kPa-92 kPa.

The propose additional criteria soft rock beside UCS and mineralogy is important aspect to get more accurate characteristic in order to minimize the mining slope risk failure.

Related to slope stability, the material soft rock in this study is divided to be 2 parts. The first part is layer soil and sandy clay with average thickness 20m, and claystone with total average thickness 40 m.

3.9 Slope Stability Analysis

The method for evaluating slope stability analysis is limit equilibrium, which mean the comparison between forces driving from mass weight of material to internal force friction force from material [18]. Slope stability analysis was performed to analyze the prediction stability of wall mining during mining process use Geostudio 2022.1 software package, parameter include topography, unit weight, cohesion, friction angle and water table. Unit weight, cohesion and friction angle refer to the material characteristic which have been explained before. Base on the material characteristic and stratigraphy, the lithology are grouped in to 5 (five) zone material include soil, sandy clay, claystone intercalated sandstone-siltstone, carbonaceous claystone and claystone as under burden (UB) as depicted as Table 8 below.

Table 8-Summary of geotechnical material properties

No	Lithology	Unit Weight (Kg/m^3)	Cohession (kPa)	Friction angle (^{0})
1	Soil	15,30	6,30	21,96
2	sandy clay	14,70	12,32	21,57
3	Claystone-sandstone	19,40	91,00	24,47
4	Claystone	18,30	77,14	21,46
5	Claystone	20,30	92,00	28,66

Base on the data above we can conclude that soil and sandy clay have the lowest strength, whereas the claystone, claystone intercalated sandstone-siltstone and claystone as under burden are more strength.

Slip failure model use Mohr-Coulomb [4, 22, 28] whereas unit weight, cohesion and friction as the slope model parameter. Water table is as pore water surface parameter, and refer to actual data measurement in piezometer hole as Table 9.

Table 9-Summary of water table measurement

No	Hole	Water table m
1	GT-06	0.32
2	GT-07	0.24
3	GT-08	0.19
4	GT-09	2.15
5	GT-10	0.50
6	GT-11	1.15

The Factor of Safety (FoS) mean ratio between shear resistance to driving force along a potential failure plane [17]. The FoS in this analysis refer to Indonesian mineral and resources ministry regulation number 1827 K30 MEM 2018 [24] which the summary as Table 10.

Table 10-FS reference for slope stability

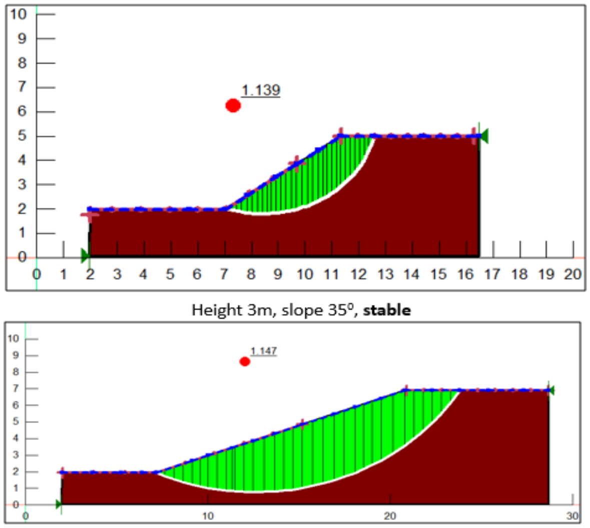
Slope	Consequence of failure	FS Static
Single	Low-high	1.1
Inter-ramp	Low	1.15-1.2
	Medium	1.2-1.3
	High	1.2-1.3
Over all	Low	1.2-1.3
	Medium	1.3
	High	1.3-1.5

Refer to FK table above and the consequence of failure is classified as high, the standard FS for single slope > 1.1, over all slope for FS static is 1.3-1.5.

3.9.1 Single Slope Stability Analysis

Single slope stability analysis was performed for soil, sandy clay, claystone intercalated sandstone-siltstone, carbonaceous claystone and claystone–under burden, water table is saturate and FS on static condition.

Soil was analyzed with geometry simulated height 3m and 5m, slope 20^0, 25^0, 30^0, 35^0. Based on slope modeling analysis, soil with height 3m will get stability within slope ≤35^0 and on height 5 m, the stability on slope ≤20^0. The model simulation for slope stability analysis on material soil-peat are depicted as picture below.

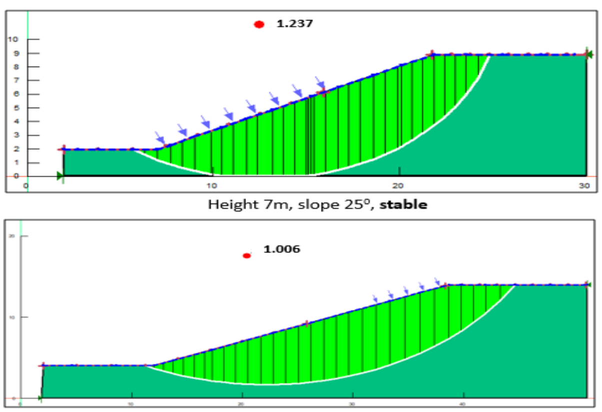


Height 3m, slope 35⁰, **stable**

Height 5m, slope 20⁰, **stable**

Figure 23-Slope stability analysis material soil

Sandy clay has been analyzed with height 7m and 10m and slope at 20⁰, 25⁰, 30⁰, and 35⁰. Based on slope stability analysis result show that the material with height 7m will get stability at slope ≤ 25⁰. And the material with height 10m, will failure start at slope 20⁰.

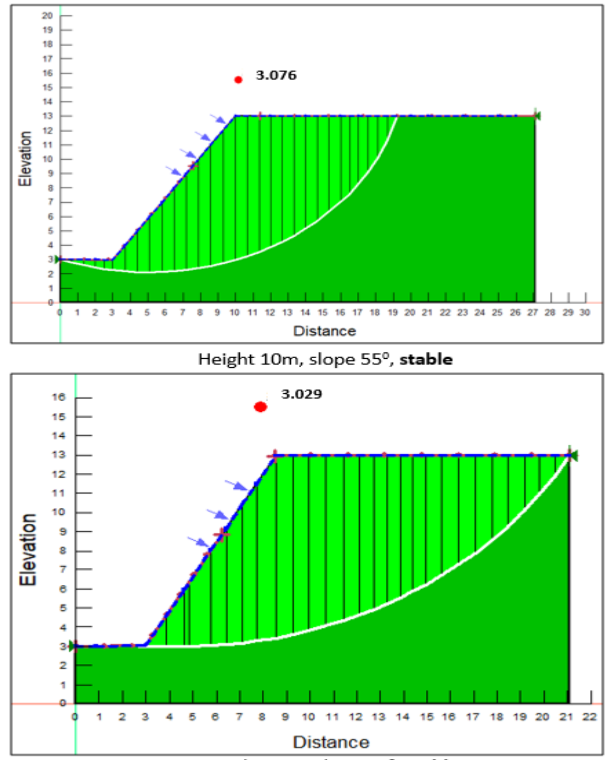


Height 7m, slope 25⁰, **stable**

Height 10m, slope 10⁰, **unstable**

Figure 24-Slope stability analysis material sandy clay

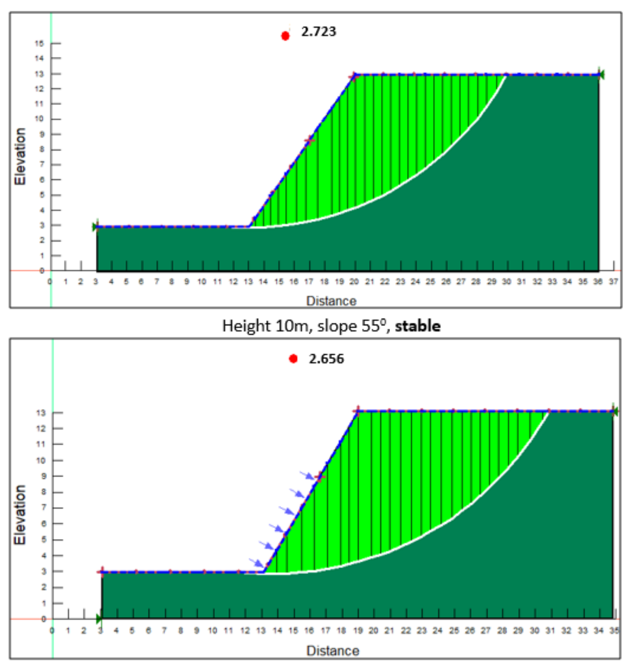
Claystone-intercalated with sandstone and siltstone have been analyzed with height 10m and slope at 50⁰, 55⁰ and 60⁰. Based on slope modeling stability analysis show that material will stable at slope 50⁰, 55⁰ and 60⁰ (Figure 25). Material claystone contains carbonaceous (CS-3) have been analyzed with height 10m and slope at 50⁰, 55⁰ and 60⁰. Based on slope modeling stability analysis show that all material will stable with slope 50⁰, 55⁰ and 60⁰ as Figure 26.



Height 10m, slope 55⁰, **stable**

Height 10m, slope 60⁰, **stable**

Figure 25-Slope stability analysis material claystone intercalated sandstone and siltstone.



Height 10m, slope 55⁰, **stable**

Height 10m, slope 60⁰, **stable**

Figure 26-Slope stability analysis material claystone

Summary single slope stability analysis on all material soil, sandy clay, claystone intercalated sandstone-siltstone, and carbonaceous claystone is depicted at Table 11.

Table 11-Summary single slope stability analysis result

No	Lithology	Slope height	Factor of Safety							
			Slope (^{0})							
		m	20	25	30	35	40	50	55	60
1	Soil	3	1,522	1,347	1,274	1,139	1,054			
		5	1,147	0,995	0,886	0,808				
2	Sandy clay	7	1,350	1,237	1,091	0,996				
		10	1,006	0,975						
3	Calystone-silstone	10						3,094	3,076	3,029
4	Claystone	10						2,751	2,723	2,656

3.9.2 Overall Slope Stability Analysis

Overall slope stability was performed to simulate the stability of slope wall mining include total height, and overall slope. Overall slope performed by construct single slope from every lithology-material.

Base on material zonation, slope stability analysis at Sesayap Coal Field overall slope was simulated for 4 model, i.e. model slope 1, model slope 2, model slope 3 and model slope 4. Model slope 1 has the total height 58m, overall slope 25^0, wide berm between material sandy clay and claystone intercalated sandstone-siltstone is 10 m. Base on this geometry, the factor of safety in static condition is 1.019 with mean unstable as Figure 27.

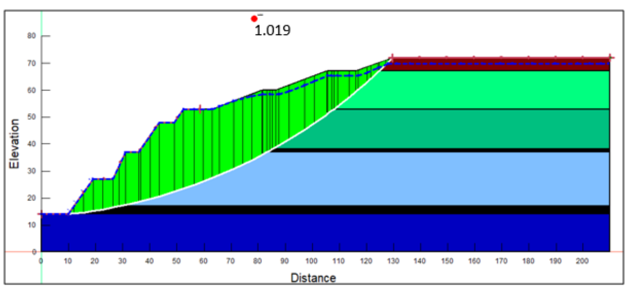


Figure 27-Slope stability analysis model slope 1

Model slope 2 configure total height 58m, overall slope 24^0, wide berm between sandy clay and claystone intercalated sandstone-siltstone is 20 m. Base on this geometry, the slope analysis modeling show the result FS on static condition is 1.102 with mean the wall is unstable as Figure 28.

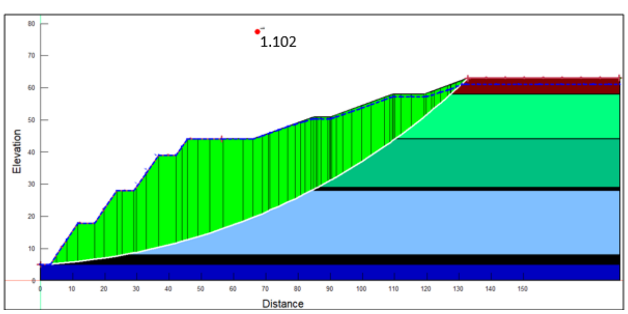


Figure 28-Slope stability analysis model slope 2

Model slope 3 configure the total height 58m, overall slope 22^0 and width berm material between toe of sandy clay and crest of compact claystone intercalated sandstone-siltstone added to be 30 m. Base on this geometry, the slope analysis modeling show the result FS on static condition is 1.199 with mean unstable as Figure 29.

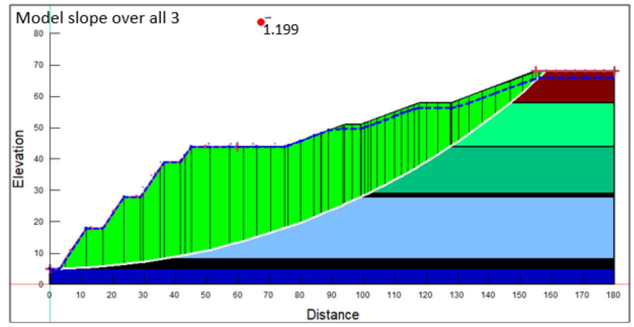


Figure 29-Slope stability analysis model slope 3

Model slope 4 configure the total height 58m, overall slope 22^0, width berm material between toe of sandy clay and crest of compact claystone intercalated sandstone-siltstone added to be 40 m. Base on this geometry, the slope analysis modeling show the result FS on static condition is 1.314 with mean stable as Figure 30.

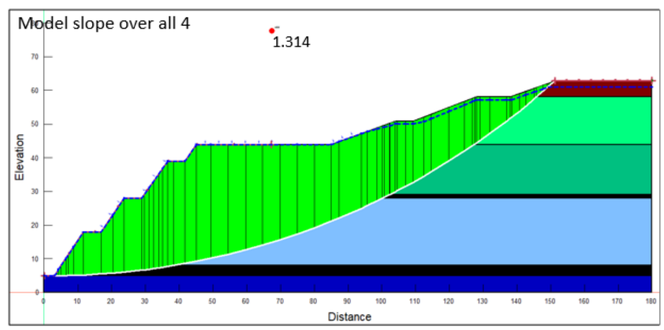


Figure 30-Slope stability analysis model slope 4

Summary result of slope stability analysis for overall slope at Sesayap field are depicted as Table 12.

Table 12-Summary over all slope stability analysis result

No	Model Slope	Total Height	Over All slope	Berm*	FS Static
		m	0	m	
1	Model 1	58	25	10	1.019
2	Model 2	58	24	20	1.102
3	Model 3	58	22	30	1.199
4	Model 4	58	21	40	1.314

From the slope analysis result can be conclude that lithology soil and sandy clay has the different geometry with claystone. Soil and sandy clay have the slope geometry height 5m, berm 10m, slope 20^0; sandy clay height 7m, berm 5m, slope 20^0. Claystone intercalated sandstone-siltstone have the geometry slope height 10m, berm 5m, slope 55^0. To get slope stability, the geometry total height 58m, overall slope 22^0, berm between sandy clay and claystone is 40m.

4.0 CONCLUSION

- The lithology performs the mining slope in Sesayap coal consist of soil, sandy clay, claystone, claystone intercalated sandstone and siltstone and carbonaceous claystone. Soil and sandy clay at interval 0m to 20m, has the loose structure, very low strength. Claystone, claystone intercalated sandstone and siltstone and carbonaceous claystone at depth 20 m to 70 m has the compact structure, low to medium strength.
- Average RQD for soil 1.36%, sandy clay 1.41%, claystone 56.14%, claystone intercalated sandstone 70.80%, carbonaceous claystone 78.59%.
- Average water content for sandy clay 46%, claystone 9%, siltstone-sandstone and carbonaceous 10%.
- The composition of minerology in sandy clay are quartz 65%, kaolinite 5% and ilite 30%. Kaolinite and illite indicated as one of trigger factor for sliding in October 2022.
- Average UCS for lithology claystone include sandy clay is 0.47 MPa, sandstone 1.23 MPa and carbonaceous claystone 1.32 MPa. Refer to ISRM 1981, all lithology at Sesayap coal field classified as Soft Rock.
- Refer to soft rock classification proposed by He (2014), with parameter clay content and UCS strength, so the material in Sesayap coal field categorized as expansive soft rock which imply under the external load applied, will face the slip along clay mineral, and any significant expansion under water.
- The relationship between RQD, water content and UCS: at interval 0 m to ±20 m, soil and sandy clay have the RQD 0% to 19%, water content range 34% to 86%, strength from 0.00 MPa to 0.12 MPa. At interval ±20 m to ±70 m, the lithology are claystone, claystone intercalated siltstone and sandstone, carbonaceous claystone as compact material have the RQD 20%-100%, water content 6% to 12%, strength from 0.12 MPa to 3.40 MPa.
- Single slope geometry for soil: height 5m, slope 20^0; sandy clay bench height 7m, slope 20^0; claystone intercalated sandstone-siltstone bench height 10 m, slope 55^0; and material claystone carbonaceous bench height 10 m, slope 55^0.
- Over all slope geometry total height 58m, overall slope 21^0, wide berm 40m, FS static 1.314.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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