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DETERMINATION OF DISPOSAL MATERIAL DENSITY IN OPEN-PIT COAL MINE DISPOSAL AREA

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ABSTRACT: This study proposes a method for determining the density of disposal material in open-pit coal mines using undisturbed sampling with a large sampler tube (LST). The disposal materials in the studied area are mostly mixed between sandstone and claystone from the coal overburden and/or interburden material in the coal open pit. The materials belong to the Warukin Formation in the southeast area of Kalimantan Island. Determination of disposal material density has become necessary since it is related to the planning of the material disposal process in the disposal area and the desire to optimize disposal capacity. The material sampling was conducted at several points in the Kusan and Girimulya disposal areas, and each point was taken at various depths. Sampling locations were also selected based on disposal age: less than 3 months (active disposal), approximately 6 months (slightly active disposal), 12 months and more (old disposal), and mining road to disposals. Additionally, the CBR test was conducted at a location near the material sampling point, where the results will be used for comparison with the density values obtained. The undisturbed sampling of disposal material was conducted using a sampler tube made of galvanized iron with a diameter of 13.3 cm. The natural bulk density is determined by following the procedure of ASTM D2937. The results show that the active Kusan disposal area has low-density material because only 10% of samples have a density equal to or greater than the optimum density, while the active Girimulya disposal area has high-density material because 70% of samples have a density equal to or greater than the optimum density. The results of the study also show that natural compaction with the existing dumping procedure can be achieved after a disposal age of approximately six months. Compared to the CBR values along its depth, the density values obtained from this method are in good trend; the proposed method can be used for monitoring the density of disposal material.

Keywords: Density of disposal material, Undisturbed sampling, Sampler tube, CBR.

1. INTRODUCTION

Coal mining in Indonesia predominantly uses the open-pit extraction method; therefore, the problems that are present are significantly related to environmental impact. One of the primary concerns is managing and optimizing the capacity of overburden and/or interburden material disposal. The management of disposal areas is particularly critical due to the substantial costs associated with land acquisition and environmental impact mitigation. A key factor influencing disposal efficiency is handling overburden and/or interburden material. The activities of excavation, transportation, and dumping activity are preceded by a loosening process, which directly decreases the disposed material's density and strength. As the volume of overburden increases due to the increasing production, effective disposal area management becomes essential in minimizing environmental disruption and ensuring long-term sustainability. Implementing advanced disposal techniques and compaction strategies can significantly enhance operational efficiency and reduce overall mining costs [1].

In general, in-situ soil density testing standards use the sand cone method [2-5] and the rubber balloon method [6], however, these methods can only determine the density of the surface part of the material layer. Other methods of In-situ soil density testing can also be applied, including the nuclear method [7], water replacement method [8], photogrammetric [9], sand replacement method [10,11], and combined electrical resistivity methods [12,13]. However, these methods still face challenges in determining soil density at various depths with accuracy. To address this challenge, a sampling method utilizing a large sampler tube (LST) will be proposed to assess the density of disposal material at various depths. This approach is aimed at providing accurate data on disposal material density characteristics for managing the overburden and/or interburden material and optimizing the disposal area utilization.

Disposal materials in the study areas are a mixture of sandstone and claystone from the overburden or interburden material in the open-pit coal mine. The materials belong to the Warukin Formation in the southeast area of Kalimantan Island. Sandstone is classified as lithic wacke within the quartz greywacke category. Based on its physical and mechanical properties, it exhibits a rock strength of less than 1 MPa and an average natural density of 2.10 g/cm^3 [14].

Claystone has a rock strength of less than 1 MPa and an average natural density of 1.89 g/cm^3 [15]. These density values are natural in situ densities when sandstone and claystone have not been excavated.

Based on the description above, this study aims to determine the density value of the material in the disposal area using the undisturbed sampling method at several depths and at various ages of disposal. Understanding density value will allow for a quick assessment, facilitating immediate improvements in disposal management. In addition, it can also determine how deep the natural compaction effect (by relying on the weight of the dump truck that passes through disposal) is currently being adopted.

2. RESEARCH SIGNIFICANCE

The density of the disposal material significantly affects to the stability of the disposal embankment. Therefore, determining the density of disposal materials in the study areas is essential. A larger sampler tube used in this undisturbed sampling method is expected to be able to accommodate the overburdened material's grain size in the disposal area. This study presents the concept of rapid sampling of waste material at various depths to determine its density values. Related to the density monitoring activity, material sampling is also conducted at various disposal ages in order to know the effect of natural compaction, relying on existing dumping procedures. The California Bearing Ratio (CBR) value, derived from Dynamic Cone Penetrometer (DCP) tests, is conducted near undisturbed sampling points to make comparisons if the density value will be brought to the issue of material compactness.

3. METHODS

3.1 Undisturbed Sampling

Undisturbed sampling is conducted quickly using an LST made of galvanized iron with 13.3 cm in diameter, 20 cm in length, and 3.5 mm in tube wall thickness. The disposal materials samples originated from rock excavation activities in the mining area, either through blasting, ripping or direct excavation in the mining area. These activities and the reality in the field are that coal-bearing strata will suffer the deterioration process, which results in the reduction of rock fragment size. Analysis of grain size distribution shows that the D_{max} value of the Kusan and Girimulya areas is 50 mm. Therefore, the LST is selected to accommodate the overburden material's grain size in the disposal area. The shape of the LST and the concept of sampling for determining the density of this material can be seen in Fig. 1.

The sampling process using an LST starts by excavating a test pit in the designated disposal area using a backhoe excavator equipped with a smooth-back bucket. The test pit dimensions are 5 m wide and 3 m deep, selected due to the excavator's operational depth. The sampler tube is then inserted at the test pit wall, starting from a depth of 0.6 m, continuing with an interval of 60 cm, and ending at a depth of 3 m. The number of sampler tubes inserted is 5 tubes. After all sampler tubes are inserted into the test pit wall and filled with material, the sampler tube is taken using the excavator and wrapped by sample stretch film wrap to maintain the natural moisture content. The sampling process at each point takes approximately 1.5 hours. After that, the sample is prepared for natural density and water content testing [16]. Sampling activities can be seen in Fig. 2 a-d.

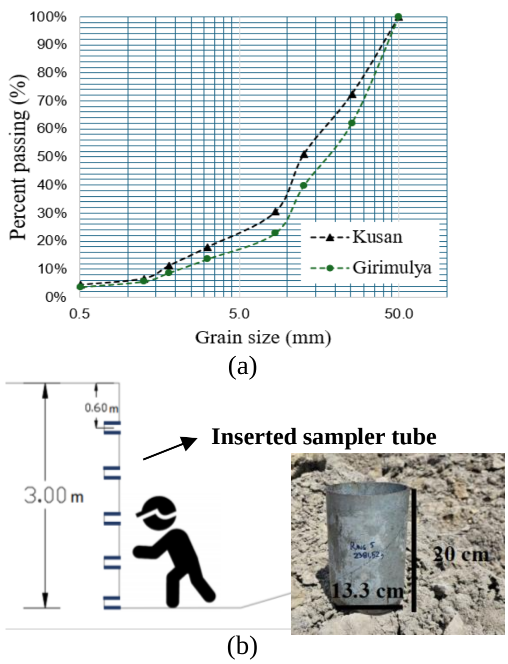


Fig. 1 (a) Grain size distribution, (b) concept of sampling and LST.

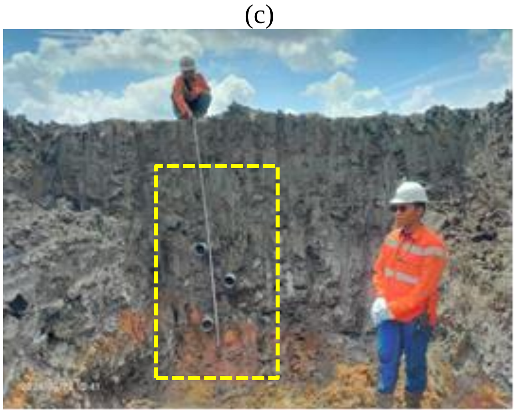
3.2 Bulk density determination

Bulk density is the mass of all solid particles in a container divided by the volume of the container [17]. Soil density, referring to the ASTM D2937 standard [16], is determined in the following stages. First, the sampler tube is weighed (with the AND Apollo GF10002A scale, which has a high level of accuracy) to obtain the weight of the empty sampler tube in units of grams (g). Second, the sampler tube containing the disposal material sample is weighed (Fig. 3). Then, the sample weight in units of (g), is obtained by subtracting the second weight with the weight of the empty sampler tube. Third, the diameter and height of the sampler tube are measured to obtain the sample volume (equal to the sampler tube volume) in units of cm^3. Fourth, the density value is calculated refers to (Eq. (1)):

(a)

(b)

(c)



(d)

Fig. 2 (a) Test pit excavation, (b) inserting the LST into the test pit wall, (c) measurement using DCP is conducted near the undisturbed sampling, (d) profiling the test pit wall.

$$\rho = m/V \quad (1)$$

Where ρ is insitu bulk density (g/cm^3), m is the sample weight (g), and V is the sample volume (cm^3). The test results from 11 test points are shown in Table 1.

Fig. 3. Sample weight measurement.

3.3 Natural Moisture Content Determination

Moisture content significantly affects the density value of disposal materials. Therefore, it is very important to accurately determine the disposal's natural moisture content value. Moisture content measurements were also conducted in the field laboratory using the same weighing instrument to weigh the natural samples and using a standard measuring cup. The samples are carefully weighed using the same weighing instrument to maintain uniformity in the measurement process. This process ensures precision and consistency in the results obtained. The samples were then dried in an oven for 24 hours (or until a constant weight, depending on the material). After the drying process is completed, the dry weight of the samples is recorded by reweighing them. The natural moisture content is determined by calculating the weight of water in the sample (wet weight minus dry weight), dividing it by the dry weight of the material, and multiplying it by 100%. The test results of the natural moisture content of disposal material from 11 test points are shown in Table 2.

4. RESULTS AND DISCUSSION

The 11 sampling points were conducted at the disposal area of Kusan and Girimulya were selected by considering the existence of two mining block areas that becoming the source of overburden or interburden materials, which have slightly different characteristics. Besides that, the disposal age was also taken into consideration. As shown in Tables 1 and 2, the samples taken from the Kusan disposal area (with code K) and Girimulya (with code G) were then grouped based on disposal age as follows: K1, K2, and G1, G2 were Kusan active disposal (disposal age less than 3 months) and Girimulya active disposal, respectively.

Table 1. Natural and dry density material disposal at each sampling area

Depth (m)	Bulk density (g/cm^3)																					
	K1		K2		G1		G2		OK6		OG6		OK1		OG1		JK1		JK2		JG	
	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D
0.6	1.79	1.48	2.05	1.75	1.97	1.70	1.95	1.64	2.02	1.74	2.00	1.78	2.06	1.88	2.11	1.79	1.86	1.60	2.00	1.70	2.08	1.87
1.2	1.80	1.55	1.79	1.55	1.80	1.48	1.83	1.45	1.94	1.59	1.82	1.57	1.95	1.64	1.98	1.64	1.91	1.67	2.06	1.78	2.11	1.83
1.8	1.70	1.48	1.77	1.52	1.77	1.51	2.00	1.73	1.85	1.54	1.84	1.61	2.08	1.80	1.94	1.67	1.87	1.65	2.08	1.84	1.96	1.65
2.4	1.59	1.41	1.81	1.55	1.78	1.59	1.88	1.52	1.95	1.62	1.72	1.63	1.93	1.65	1.94	1.62	1.85	1.63	1.91	1.62	2.09	1.82
3.0	1.60	1.41	1.68	1.41	1.76	1.49	2.09	1.72	1.96	1.63	1.82	1.53	1.90	1.63	1.83	1.52	1.82	1.60	2.02	1.69	2.00	1.69

Table 2. The natural moisture content of the material disposal

Depth (m)	Natural Moisture Content (%)										
	K1	K2	G1	G2	OK6	OG6	OK1	OG1	JK1	JK2	JG
0.6	17.4	14.4	15.3	16.3	13.9	15.0	8.8	11.4	14.2	15.3	10.4
1.2	14.2	13.8	17.1	18.4	14.1	14.0	15.6	13.5	12.1	13.5	13.0
1.8	12.8	14.3	13.9	13.6	15.6	13.4	13.6	12.9	11.9	11.7	15.5
2.4	11.1	14.2	16.5	16.8	14.8	10.6	14.7	8.5	12.3	15.1	12.9
3.0	12.2	13.8	16.8	15.7	13.1	13.3	13.3	13.8	12.2	16.0	15.6

Still related to Tabel 1 and 2, OK6 and OG6 were the sample from Kusan slightly active disposal (disposal age of approximately six months) and Girimulya slightly active disposal. Meanwhile, OK1 and OG1 were the samples from Kusan old disposal (disposal age more than 12 months) and Girimulya old disposal. Besides the disposal age, the amount of traffic, that can be used to reflect the different compaction processes, was also considered. Therefore, several sampling points were also conducted at the area of the mining road to these disposals, which were JK1, JK2, and JG for Kusan and Girimulya, respectively.

The abbreviations N, D in Table 1 stand for Natural and Dry respectively. Meanwhile, ND, DD, MC in Table 3, were stand for Natural Density, Dry Density, and Moisture Content, respectively. The data of in-situ material before mining from Kusan and Girimulya areas based on lithology (resulted from the company geotechnical laboratory tests, shown in Table 3) were intended to validate the dry density obtained this test results. It can be seen from Tables 1 and 3, that the dry density value of the disposal material is smaller than the dry density value of in-situ material.

To obtain an overview of the disposal material's density, the obtained density of disposal material will be compared to the laboratory compaction test result (reported by company's geotechnic department, shown in Table 4) and also CBR value resulted from DCP test [18].

The soil density standard of embankment intended for infrastructure is 95% of the maximum dry density obtained from a laboratory compaction test [19]. From the dry density resulted from the laboratory compaction test (shown in Table 4), the maximum dry density (MDD) can be determined, however, the graph showing the relationship between MC and DD must be developed first. The MDD is then determined by seeking the peak value of the graph. Developing of the graph showing relationship between DD and MC was attempted using the 5th degree polynomial equation refers to (Eq. (2)):

$$y = ax^5 + bx^4 + cx^3 + dx^2 + ex + f \quad (2)$$

Where y is dry density (g/cm^3), and x is moisture content (%), a, b, c, d, e, and f are coefficients determined based on data. By knowing the equation coefficients, MDD and Optimum Moisture Content (OMC) values can then be determined by calculating y'= 0. Before selecting the 5th degree polynomial equation, the graph was also estimated by 2nd - 4th degree polynomial equations, and the results were given in Table 5. However, after using the root mean square error (RMSE) and coefficient of determination (R^2) for selecting the optimum graph, the 5th degree polynomial equation was selected because, the RMSE value = 0 and R^2 value approaches 1. If the R^2 values closer to 1, the model can represent the variation in existing data [20].

Based on the 5th degree polynomial result shown in Table 5, Kusan's MDD is 1.671 g/cm^3 for mixed materials and 95% of that value the optimum disposal density is 1.587 g/cm^3. Meanwhile, Girimulya's MDD is 1.605 g/cm^3 and 95% of the MDD is 1.525 g/cm^3.

After knowing the above values, the measurement results shown in Table 1 are then plotted into a graph displayed in Fig. 4 to obtain an overview of the distribution of dry density data against the depth of each disposal areas, which are Kusan (Fig. 4a) and Girimulya (Fig. 4b).

Table 3. Density and moisture content of in situ materials based on lithology

Lithology	Kusan			Girimulya		
	ND (g/cm^3)	DD (g/cm^3)	MC (%)	ND (g/cm^3)	DD (g/cm^3)	MC (%)
Claystone	2.12	1.84	15.84	2.11	1.83	15.84
Sandstone	2.11	1.85	14.20	2.03	1.73	17.34
Siltstone	2.18	1.93	13.33	2.20	1.97	11.77
Coal	1.33	1.09	24.33	1.22	0.93	31.77

Table 4. Compaction test

No.	Kusan		Girimulya	
	DD (g/cm^3)	MC (%)	DD (g/cm^3)	MC (%)
1	1.62	11.57	1.49	12.40
2	1.64	15.06	1.56	14.66
3	1.67	17.07	1.61	18.17
4	1.60	20.63	1.54	21.79
5	1.54	22.48	1.48	23.47
6	1.47	25.23	1.32	26.45

Table 5. RMSE and R^2 values from the compaction test

Model	MDD (g/cm^3)		OMC (%)		RMSE		R^2	
	K	G	K	G	K	G	K	G
2nd Degree Polynomial	1.652	1.602	15.626	17.832	0.0109	0.003	0.973	0.998
3rd Degree Polynomial	1.656	1.604	15.503	17.724	0.0105	0.002	0.975	0.999
4th Degree Polynomial	1.661	1.606	17.269	17.882	0.0046	0.0008	0.995	0.999
5th Degree Polynomial	1.671	1.605	17.201	17.979	0.000	0.0000	0.997	1.000

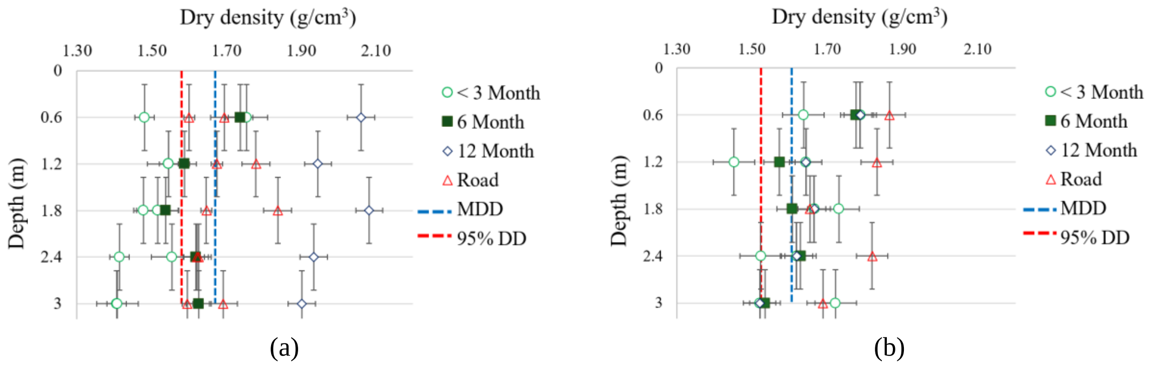
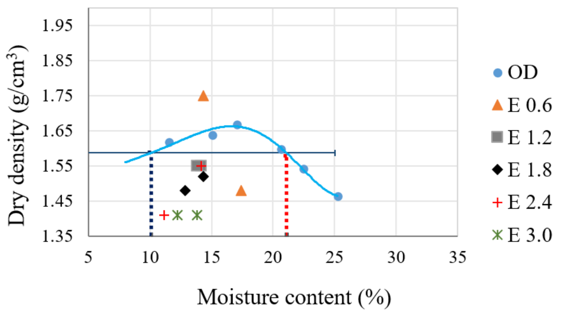


Fig. 4 Correlation of depth and density, (a) Kusan area and (b) Girimulya area.

Based on Fig. 4a, the Kusan area shows that the active disposal area is dominated by material with a density value less than 1.587 g/cm^3, only 10% (1 data from 10 samples) meet the optimum density criteria. The optimum density of soil refers to the maximum dry density that can be achieved when the optimum moisture content. This means that the natural compaction process in the active Kusan disposal area has not formed yet. Meanwhile, the material in the slightly active disposal area has 80% (4 data from 5 samples) density value greater than 1.587 g/cm^3. This has a meaning that the natural compaction process at this location has formed.

Referring Fig. 4b of the Girimulya's disposal area, it can be seen that the active disposal area has 70% (7 data from 10 samples) material that has a density value greater than 1.525 g/cm^3. This fact shows that the natural compaction process has taken place in the active Girimulya disposal area. Similarly, materials in the slightly active and older disposal areas are dominated by material that has density value greater than 1.587 g/cm^3 (4 data from 5 samples).



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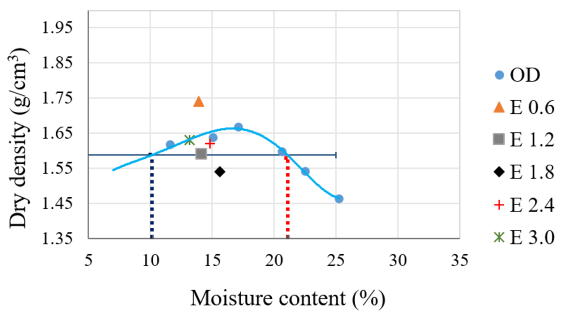

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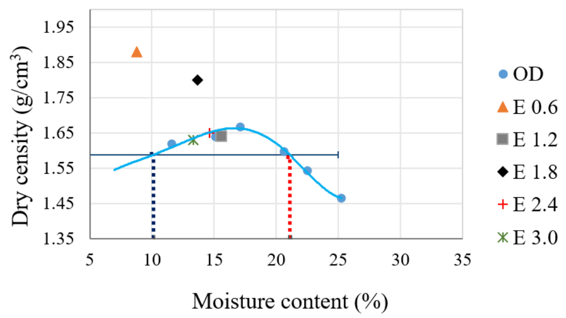

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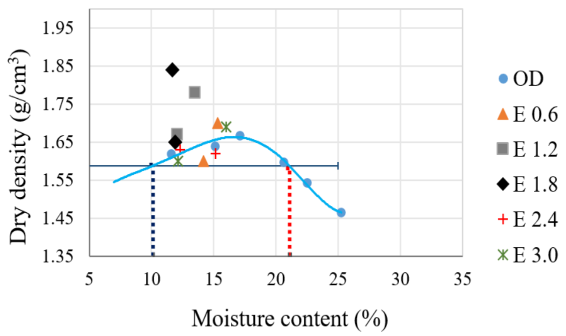


(d)

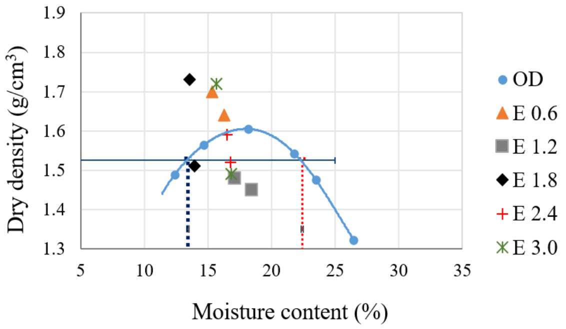
Fig. 5 Relationship between DD and MC of material from Kusan disposal area for each depth, (a) < 3 months, (b) 6 months, (c) 12 months, and (d) mining hauling road Kusan's area.

The obtained DD (Table 1) and MC (Table 2) are also plotted together with the results of the laboratory compaction test in order to obtain an overview of the distribution against depth at each disposal location, which is shown in Fig. 5 for the Kusan area and Fig. 6 for the Girimulya area.

Fig. 5 a-d shows the plot of the resulted DD and MC of material from Kusan's disposal area based on the age of disposal. The light blue line is the graph showing the relationship between DD and MC resulting from the laboratory compaction test of the mixed disposal material (sand and clay) taken from Kusan's disposal area, which has been smoothed using 5th degree polynomial. The horizontal line shows the optimum dry density (ODD) required for the embankment, which is calculated as 95% of the MDD. Subsequently, the red and blue vertical dashed lines show the MC value at the ODD value. The symbol described by (E) in the Figure-legend are explaining the depth of the sampling position. From Fig. 5a, it can be seen that the obtained DD from active disposal is dominantly below the ODD. Fig. 5b, however, the DD of material taken from the slightly active disposal area has mostly increased compared to the active disposal. Then, from Fig. 5c, it can be seen that the DD of the old disposal material is greater than the ODD. Based on this finding, it can be interpreted that natural compaction, which occurs over time, can be demonstrated through this research procedure. The natural compaction (due to the dump truck weight passing through the disposal area and the weight of the material itself) will be achieved after around 6 months. However, another condition, as shown in Fig. 5d, is that all DD of material taken from the disposal hauling road is greater than the ODD. This indicates that the compaction process in the disposal hauling road area, whether it occurs naturally (due to the dump truck weight) and/or due to mechanical compaction (using the designated compactor), has been effectively achieved.

Fig. 6 a-d shows the plot of the resulted DD and MC of material from Girimulya's disposal area based on the disposal age. The light blue line is the graph showing the relationship between DD and MC resulting from the laboratory compaction test of the mixed disposal material (sand and clay) taken from Girimulya's disposal area, which has been smoothed using the 5th degree polynomial. The horizontal line shows the optimum dry density (ODD) required for the embankment, which is calculated as 95% of the MDD. Subsequently, the red and blue vertical dashed lines show the MC value at 95% of the MDD value. The symbol described by (E) in the Figure-legend explains the depth of the sampling position. From Fig. 6a, it can be seen that the obtained DD from active disposal is dominantly below the ODD. However, from Fig. 6b and 6c, the DD of material taken from the slightly active disposal area and the old area has increased to greater than the ODD. Based on this finding, it can be interpreted that natural compaction due to the dump truck weight passing through the disposal area has been effectively achieved for Girimulya's material. The results in Fig. 6d show that all DD of material taken from the disposal hauling road is greater than the ODD.

Therefore, this indicates that the compaction process in the disposal hauling road area, whether it occurs naturally (due to the dump truck weight) and/or due to mechanical compaction (using the designated compactor), is sufficient for Girimulyas's material.



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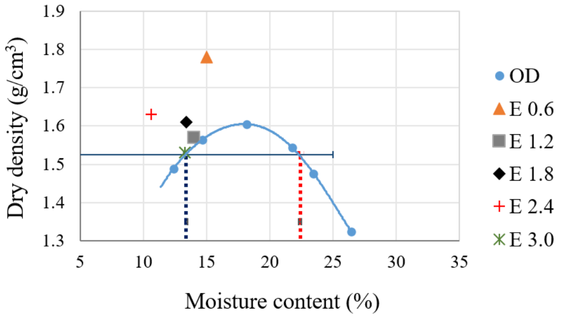

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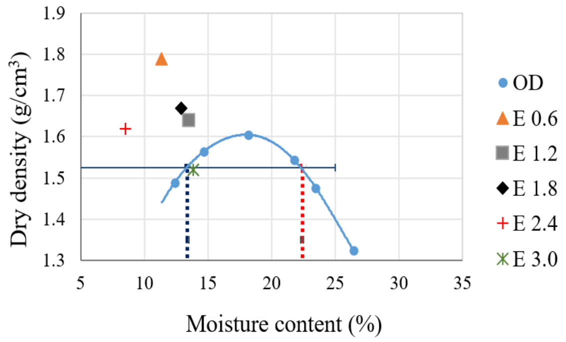

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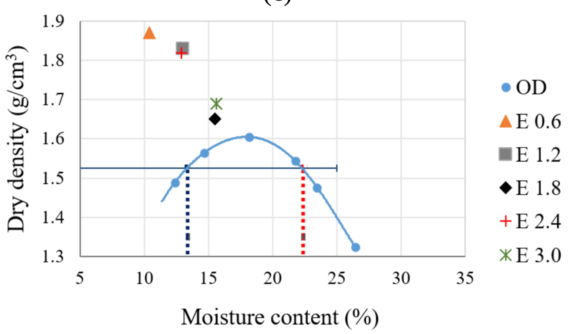

(d)

Fig. 6 Relationship between DD and MC of material from Girimulya disposal area for each depth, (a) < 3 months, (b) 6 months, (c) 12 months, and (d) mining hauling road Girimulya area.

To ensure that the results obtained from this study are correct, besides making comparisons between the disposal material density in Table 1 and the in-situ density in Table 3, the results of DD are then compared with the results of the DCP test, which had been converted to the CBR value [18]. The DCP test was conducted in the same area, near the sampling point, to determine the disposal material density, and the data were collected from every meter to a depth of 3 meters. The DD values (especially the MDD value) generally correlated with CBR values, which means that as MDD increases, CBR also increases [21]. The obtained DD (Table 1) is then plotted together with the CBR values resulting from the DCP tests against the depth at each disposal location, which are shown in Fig. 7 for the Kusan area and Fig. 8 for the Girimulya area.

The conversion equation from DCP to CBR values refers to (Eq. (3)):

$$Log\ (\mathrm{CBR}) = \alpha - \beta \text{ x } Log\ (\mathrm{DCP}) \qquad (3)$$

Were α = intercept and $-\beta$ = slope from the graph of the relationship between DCP value and CBR value.

From Fig. 7 a-d, it can be seen that the DD values (blue curve) have a good trend with the CBR values (green curve). This is in accordance with the correlation expressed above. Besides that, from Fig. 7 a-b, it can be seen that at a depth of 0.6 m in the active and slightly active disposal of the Kusan area, the CBR value is relatively high, between 42.34-42.73%, and the DD value is also relatively high at 1.74-1.75 g/cm3, which means that the disposal material at this depth has a high bearing capacity. From Fig. 7 a-b, it can be seen that up to a depth of 3m, both the DD value and the CBR value decreased, even though at a depth of 2.4 m, they slightly increased, which means that the compaction process at both ages of the disposal embankment only occurred up to a depth of 0.6 m.

Fig. 7c, shows the plot of the DD value and the CBR value of the material at the old disposal, which tends to have the same pattern, where the high CBR value and the DD value occur at a depth of 0.6 m. When this value is compared to the two previous disposal ages, both values in this disposal embankment show a slight increase. Meanwhile, in the hauling road area shown in Fig. 7d, even though it still has the same pattern, there is a difference in the DD distribution based on depth, that on near the surface, the value is not so high (but still greater than Kusan's ODD) and smaller than the old disposal. However, at a depth of 1.2 m, both values increase, becoming greater than the point near the surface and greater than the values at the old disposal. This case is because the sample JK1 was taken on the hauling road, which is located in the disposal area, which was 3-6 months old.

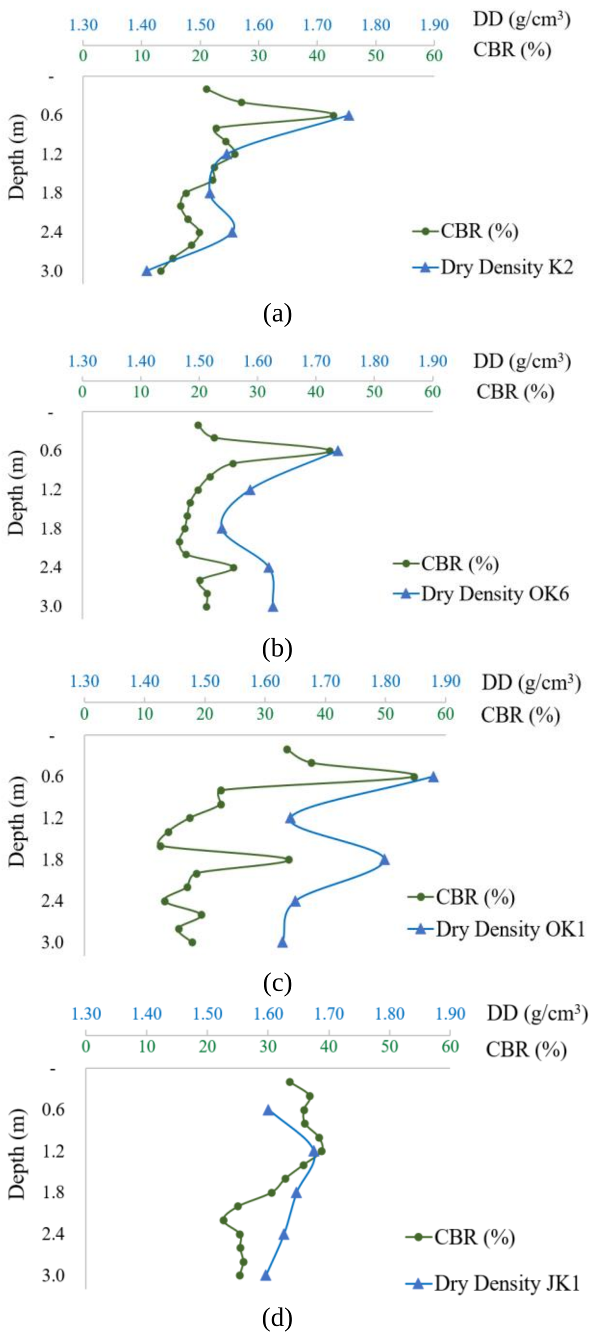

Fig. 7. Distribution of the DD value and the CBR against the depth in Kusan disposal area, (a) < 3 months, (b) 6 months, (c) 12 months, and (d) mining hauling road.

Fig. 8 a-c shows the plot of DD and CBR values obtained from the Girimulya's disposal material against depth. The green line is the CBR value (%), and the blue line is the DD value. From Fig. 8 a-c, it can be seen that the high DD value appears at a depth of 0.6 m then decreases and at a depth of around 2.4m for active and slightly active disposal and around 1.8 m for old disposal, it increases slighly then decreases again to a depth of 3m, which is also confirmed by the CBR values.

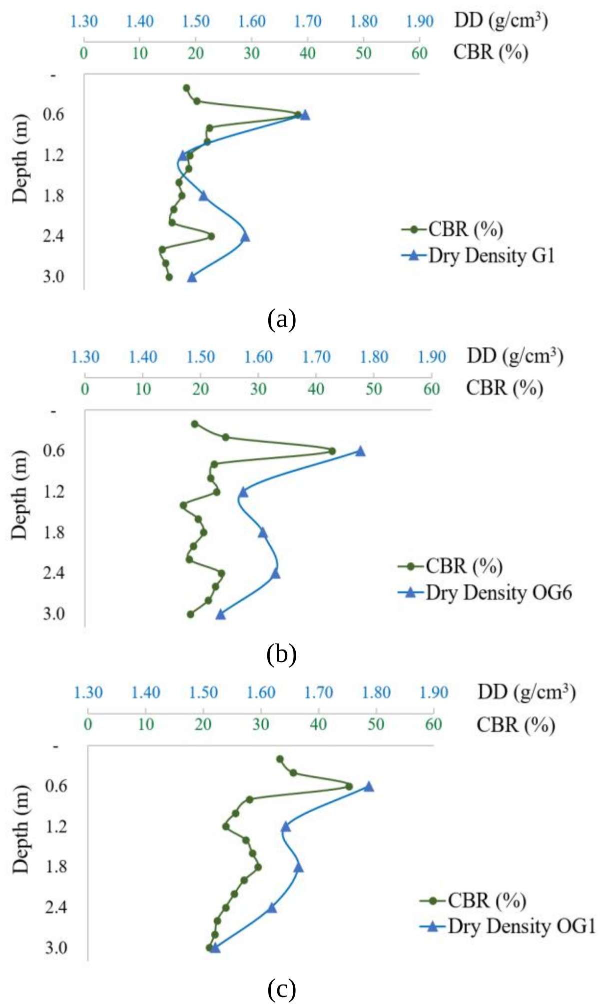

Fig. 8. Distribution of the DD value and the CBR against the depth in Girimulya disposal area, (a) < 3 months, (b) 6 months, (c) 12 months.

A correlation graph of dry density and CBR values was created to increase confidence. Fig. 9 shows the correlation between dry density and CBR values in the Kusan area and Fig. 10 shows the correlation between dry density and CBR values in Girimulya area.

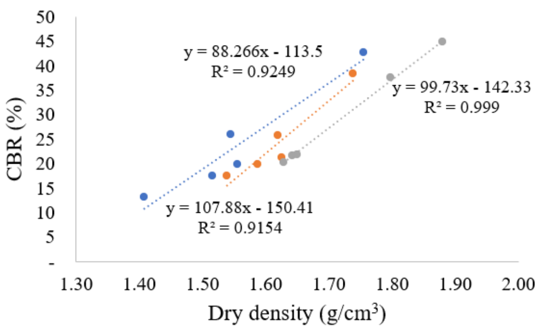

Fig. 9. The correlation between dry density and CBR values Kusan disposal area.

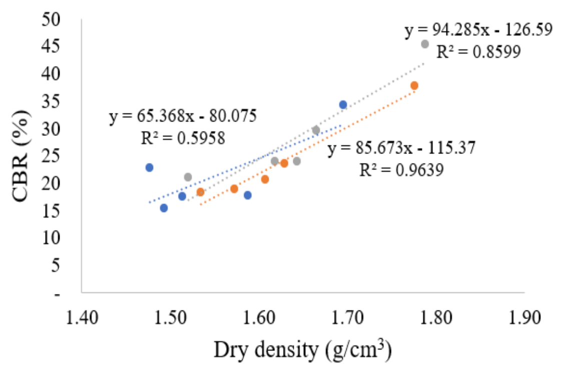

Fig. 10. The correlation between dry density and CBR values Girimulya disposal area.

The analysis results show on Fig. 9 and Fig. 10 that the relationship between dry density and CBR has an R^2 value ranging from 0.59 to 0.99, indicating a good correlation.

According to these findings, the proposed method for determining the density of disposal material, which started with undisturbed sampling using an LST in the test pit wall and then continued with ND, DD, and MC measurements in the laboratory (referring to the ASTM D7263-21), is expected to be accepted.

The determination of material disposal density is conducted on material that can still be excavated, the grain size of which can still be represented by the diameter of the sampling tube, and does not discuss costs. Opportunities for further research include density determinations for various materials and at different depths.

5. CONCLUSION

The optimum dry density level in the active Kusan disposal area has not been achieved because only 10% of the DD value is equal to or greater than the ODD value. However, it has been achieved in the slightly active and old Kusan disposal area. Meanwhile, in the active Girimulya area, the ODD has been achieved because 70% of the DD value is equal to or greater than the ODD value.

The natural compaction process, which relies on the weight of the dump truck in the disposal material of the Kusan and Girimulya areas, occurs after 6 months and only in the range of 0.6 – 1.2 m from the surface.

After confirming the density of in-situ material and the CBR value, the proposed undisturbed sampling method using an LST is expected to be applied to take samples at the wall of the test-pit, which is excavated in the material disposal embankment for determining the disposal material density at the designated depth. Provided that the obtained density is to be used for addressing the material compactness issues, the DCP test is suggested to be conducted near the test-pit wall, where the results will be converted into a CBR value.

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