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Modification of Dumping Method by Reducing Dumping Height and Increasing Material Compaction to Increase Waste Dump Capacity in Coal Mining

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ABSTRACT

Effective waste dump management in coal mining industry is essential for reducing operational costs and optimizing waste dump capacity. One major issue faced by coal mining companies is the limited waste dump capacity due to weak strength material of sedimentary rock. This research explores the effect of modifying the dumping method by reducing the dumping height and increasing compaction by mining heavy equipment to enhance the stability and capacity of the waste dump. The existing waste dump laboratory testing data is statistically processed to determine the relationship between compaction rate (represent as material density) and strength of the waste dump material. A field experiment was conducted using a Design of Experiment (DOE) approach to analyze the impact of different compaction techniques. The study tested three factors: compaction equipment, the number of passes, and the depth of density sampling. Laboratory tests were performed on waste dump materials to evaluate changes in material compaction. A geotechnical simulation was carried out to assess the stability of the waste dump before and after compaction improvements. Regression analysis of existing waste dump data indicated a strong correlation between higher density values and improved UCS, cohesion, and internal friction angle. Field trials demonstrated that reducing the dumping layer height from 5 meters to 2 meters, combined with 20 to 30 passes of a 20-ton compactor or heavy dump truck, effectively increased the density and strength of the waste dump material from sedimentary rock. Geotechnical simulations confirmed that these improvements allowed for a steeper waste dump slope, increasing the overall slope angle from 6° to 7.5° while maintaining a Factor of Safety (FoS) of 1.32. As a result, the waste dump capacity increased from 5,444,097 BCM to 7,249,037 BCM.

Keywords: Waste Dump, Compaction, Coal Mining, Slope Stability, Operational Cost Optimization.

INTRODUCTION

For coal mining companies, managing operating costs is critically important to achieve sustainability and profitability of their operations. However, with the uncertainty of coal prices, mining companies need to focus on cost-effective strategies and accurate price prediction and regulation (Ozdemir & Kumral, 2019). For a company to remain competitive, it needs to prioritize

operational cost reduction, as a simple 2-3% reduction can result in substantial savings, given the scale of mining operations that can be worth millions of dollars (Afrapoli et al., 2021).

One significant contributor to mining costs is the geometry of the waste dump, which directly affects the distance and cost of transporting waste material. Coal loading and transportation activities typically account for 50-60% of total operating costs (Mamani et al., 2023; Afrapoli et al., 2021; Torres et al., 2020). Therefore, effective waste management, including optimizing waste dump geometry and reducing hauling distances, is critical to improve economic outcomes (Kuckartz et al., 2022). Strategic planning aims to maximize the Net Present Value (NPV) of the project using conventional methods integrated into a long-term schedule, in contrast, tactical planning focuses on material-specific strategies to achieve these goals (Das et al., 2023).

Reducing transportation distances by planning the waste dump sequence can significantly lower operational costs, as shorter distances reduce diesel consumption (Das et al., 2023; Puell Ortiz, 2017). In-pit dump offers a cost-effective solution but requires a robust scientific and practical approach to ensure its stability and capacity (Gupte et al., 2013). Increasing waste dump capacity through steeper and higher waste dump geometries is also important, as waste dump areas typically occupy 30-50% of the open-pit mine area (Tao et al., 2018). However, ensuring the stability of these structures is critical to avoid dangerous slope failures (Poulsen et al., 2013).

The stability of waste dumps depends on factors such as the strength of the dump material, topography, groundwater dynamics, drainage, and compaction processes. The mechanical strength of loose rock soils in landfills is influenced by parameters such as friction angle and cohesion (c and ϕ), as well as external factors such as drainage, seismic activity, and waste dump construction processes (Poulsen et al., 2013; Darling, 2011).

Compaction methods play a pivotal role in the evolution of waste dump properties. The rate and magnitude of compaction depend on the composition of refuse and operational practices, particularly in layer placement and controlled compression (Shariatmadari et al., 2009; Olesiak, 2020). Higher compaction pressures improve physical and mechanical properties, enhancing material stability (Rosli et al., 2019; Bruno et al., 2016). Compaction is achieved through engineered processes, as well as natural compaction facilitated by mining vehicle movement. The repetitive passage of heavy equipment disrupts particle contact points, leading to particle rearrangement and a denser material structure (Hills, 1994; Darling, 2011). Evidence of this compaction effect can be observed at depths of up to 2 meters (Darling, 2011). Several methods of construction of the dump can be seen in figure 1. Based on Blight (2009) in the book "Geotechnical Engineering for Mine Waste Storage Facilities", Traffic compaction is the process of compaction of granular or particulate material that occurs indirectly as a result of vehicles passing over the surface of the material, although this compaction is not the primary purpose of activities such as transporting or dumping the material (Blight, 2009).

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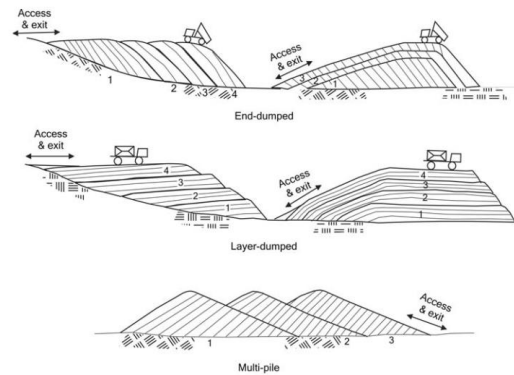


Figure 1. Various forms of waste dump construction (Blight, 2009)

To quantify the degree of compaction in a soil sample, a measure of its dry unit weight is employed (Das, 2007). The potential for significant restructuring of the internal composition of solid waste components, driven by high levels of compression, can result in increased density of the solid matter (Hanson et al., 2010). Although engineered compaction layers are typically produced by a specialized process, some waste compaction can be achieved using shorter elevation increments to enhance the natural compaction that occurs as mining vehicles traverse the surface (Darling, 2011). The passage of large mining equipment back and forth will affect the compactive energy of the waste materials. This will result in the disruption of inter-particle contact points and subsequent rearrangement of the particles, leading to the formation of a denser material (Hills, 1994). Indications of compaction by the dump hauler can be observed at a depth of 2 meters (Darling, 2011).

However, in reality, many mining companies experience an increase in distance due to a lack of disposal capacity. Although the company has a short-distance waste dump area, the capacity is not optimal. The capacity of the disposal cannot be increased due to limitations on the strength of the waste dump material. Increasing the strength of the material from the operational aspect of the dumping method has not been considered in developing the waste dump design. The increase in material strength from the load of equipment in the waste dump area has not been predicted.

This research is important to optimize the waste dump capacity so that mining operational costs can be minimized. Heavy equipment traffic movements during dumping operations need to be considered so that compaction of the dump material can be optimized. Compaction of the dump has an influence on the strength of the dump material. Therefore, this research aims to explore how the relationship between changes in dumping methods results in compaction of the dump material and helps increase the strength of the dump material in open pit coal mine waste dumps. By increasing the strength of the dump material, the waste dump design can be enforced and increase the capacity of the disposal. This can also have an impact on reducing the cost of hauling the disposal material by optimizing the capacity of the short-distance waste dump.

RESEARCH METHOD

To approach the research design used in the study, the author will use the Research Onion framework (figure 2) introduced by Saunders et al. in their book entitled 'Research Methods for Business Students'. The six layers of the research onion outline the essential components that must be understood and determined when conducting or evaluating a study. These layers include Time Horizon, Data Collection, Analysis, Methodological Decisions, Research Strategy, Research Philosophy, and Research Approach. With entities in the external layer influencing, making decisions, and providing the basis for the selection of entities in the internal layer, the process starts from the external layer and moves towards the latter.

This research is conducted with a quantitative approach on measurable data and can be processed statistically. The data used in this research comes from 143 populations of density test results of waste dump materials that have been dumped with the 5 meters dumping method. From this data, some samples have been taken for further laboratory tests to test the strength of the material. Material strength is represented by the results of UCS, Triaxial UU and Direct Shear laboratory tests. In addition to using the current disposal samples, the study also used samples from trial compaction in the field using a compactor and heavy equipment track (Heavy Dump Truck). The number of samples taken corresponds to the number of trials conducted on 10 passes, 20 passes, and 30 passes with each trial taking 4 samples for density testing.

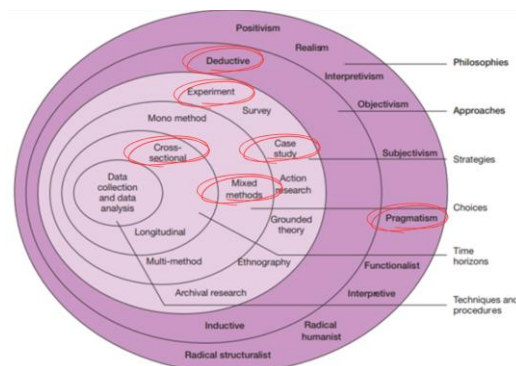


Figure 2. The Research Onion Framework (Saunders et al, 2007)

The waste dump material in the research area is sedimentary rock from the Warukin formation. The Warukin Formation is composed of quartz sandstone and claystone with shale, coal, and limestone inserts, having an age of Middle Miocene to Late Miocene (Rustandi et al, 1995). The Warukin Formation, the main geological unit in the Asam-Asam sub-basin, is characterised by abundant coal resources and widespread claystone as one of its dominant lithology's (Supandi et al., 2019).

The instrument used to compact the waste dump material is a Cat CS79B compactor with a weight of 20T and a Cat 777 heavy dump truck which has a capacity of 98.2 tons (Figure 3). In the density test, the testing material uses ring samples, ovens, scales, and cups. DCP equipment is used to determine the level of compaction based on the CBR value.



Figure 3. Heavy equipment used in the research

Source: www.cat.com

In the initial stage of the research, laboratory data processing was conducted from the current waste dump to determine the density and compaction values. The density data underwent a normality test to ensure the statistical basis of the data was met. Subsequently, correlation and regression analysis were performed to determine the relationship between compaction, represented by density values, and other geotechnical parameters such as moisture content and material strength.

The maximum compaction value was obtained through laboratory compaction tests, indicated by the moisture content and density at maximum compaction conditions. The results of the maximum compaction test will serve as a reference in determining the current compaction rate of the waste dump and trials to increase compaction values using a 20-ton compactor and a 100-ton hauler.

The selection of compaction equipment was based on the availability of the equipment in the operational area of the mining research site and considering the thickness of the waste layers. The 20-ton compactor is the heaviest compactor available in the study area. The type of compactor used in the testing is the Cat CS79B compactor. This compactor has a static weight of 13,612 kg and an operating weight when vibrating of 20,220 kg. The compactor features a drum width of 2,134 mm with a Static Linear Load value of 63.8 kg/cm.

The heavy dump truck unit has an impact on compaction because it generates greater ground pressure than the 20-ton compactor and has a wheel cross-section close to that of the 20-ton compactor's drum. Operationally, the movement of the hauler units over the waste pile during dumping provides compaction into the waste body. The heavy dump truck used in the research area is the Cat 777, which has a capacity of 98.2 tons. With an empty weight of 65,149 kg, the total weight of this heavy dump truck is approximately 165 tons. The load distribution on this type of heavy dump truck when fully loaded is divided into 30% on the front wheels and 70% on the rear wheels. With a rear wheel width of about 1,600 mm (two 27.00R49 tires), it provides sufficient ground pressure for the load on the waste material.

A two-meter-thick layer was used in the trial, considering that this thickness is the thinnest operational layer that can be formed using a 785 hauler and a 385 dozer working in the waste area. Forming thinner layers is operationally difficult during dumping as it would cause the dozer to work harder due to the longer push distances for the material. Additionally, thinner material layers being traversed by the hauler pose a risk of the unit getting stuck.

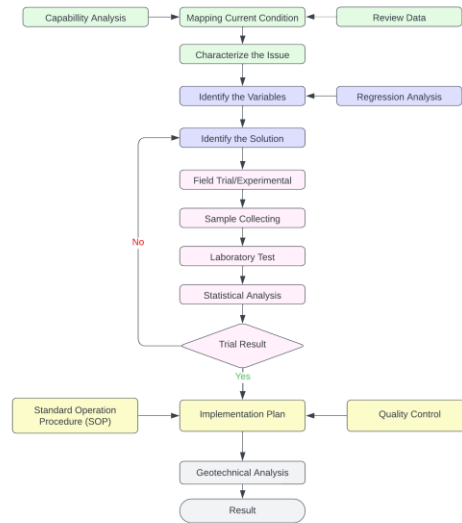


Figure 4. Research Design Diagram

The compaction of waste material complies with Indonesian government regulations regarding Guidelines for the Implementation of Good Mining Practices. According to these regulations, compaction of overburden piles using the bottom-up method is conducted gradually with a compactor or hauling equipment, with a maximum layer thickness of 1/3 of the haul equipment height (Ministry of Energy and Mineral Resources, 2018). Therefore, the chosen compaction method complies with the applicable regulatory requirements.

The trial testing was conducted at various numbers of passes: 10 passes, 20 passes, and 30 passes. This was done to determine the relationship between the number of passes and the compaction level. For each trial, 4 samples were taken using ring samples for laboratory testing of density values. DCP testing was also conducted for each number of passes to determine compaction values based on CBR values. All the process of research can be seen on figure 4.

RESULT AND DISCUSSION

Mapping the Current Condition

Data processing was conducted using a population of 143 results from material density tests on waste dumps dumped using the 5-meter dumping method (Appendices A). The normality test for the dry density values produced a P-value of 0.150, indicating that the data follows a normal distribution (Figure 5).

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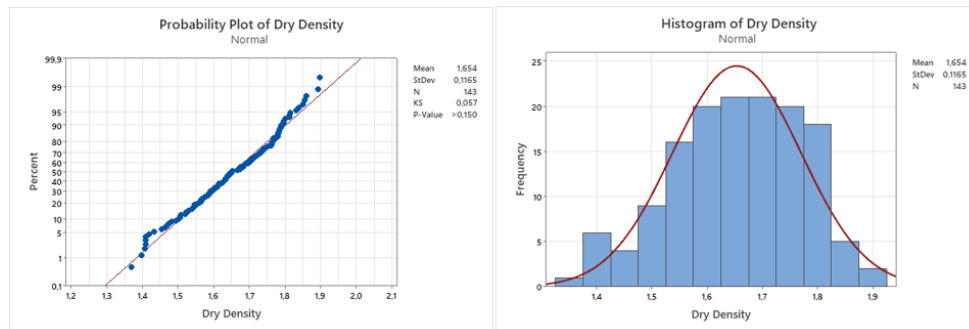


Figure 5. Normality test result of density data

A capability analysis process is carried out using Minitab statistical software to assess the current level of compaction in the existing waste dump based on the results of laboratory tests on dry density values. The lower limit (LSL) used to analyze the current condition uses a compaction value of 85% or equivalent to a density value of 1.604 g/cm³, and the target is at a compaction value of 90% or equivalent to a density value of 1.72 g/cm³. The upper limit is not specified, so the highest data value or maximum compaction data is adjusted.

The Process Capability results for the current compaction or density value show that the current process has a very low value to meet the specified density value (Figure 4.4). In order to reach the desired increase in waste dump volume, a lower specification limit (LSL) of 1,604 g/cm³ is required, with a target of 1,720 g/cm³. However, the process average (mean) of 1.654 g/cm³ shows that the process is shifting towards being lower than the target. The standard deviation value of 0.1165 reflects the level of variation in the process.

Analysis

The waste dump design is not optimal due to the low strength value of the waste dump material from laboratory tests. To prove that density influences material strength, correlation and regression analyses were conducted. Material strength is represented in the values of compressive strength, cohesion, and inner friction angle. The compressive strength value is obtained based on the UCS test results, and the cohesion and deep friction angle results are obtained from the direct shear test results.

The regression analysis results show that UCS has a non-linear relationship with Dry Density, where the regression model has an R-squared value of 70.57% of the variation in UCS test results (Figure IV.5). The adjusted R-squared value (69.65%) gives a more conservative result, but still indicates that the model is of good quality. However, the approximately 29.43% variation in the overall UCS, with a significant P-value of 0.000, suggests that this relationship does not result from chance. Approximately 29.43% of the variation in UCS indicates that other factors outside of Dry Density influence UCS values. The standard deviation of the residuals of 127.245 indicates that the deviation between the model predictions and actual values is relatively small, making the model reasonably accurate.

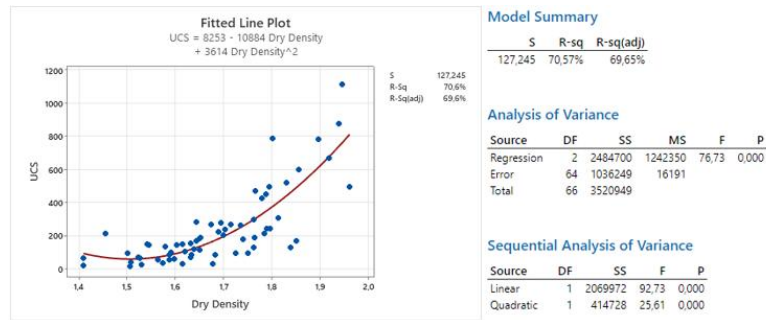


Figure 6. Regression analysis result of dry density vs UCS

The regression analysis results show that the relationship between the Cohesion and dry density variables in the model can be explained moderately (Figure IV.6). The model has an R-squared value of 63.49%, which means that about 63.49% of the variation in the data can be explained by the model. In contrast, about 36.51% of the rest are influenced by other factors outside the model. This result can be explained by the cohesion strength value, which is not alone but relates to the deep shear angle value and material composition. After adjusting for the number of variables in the model, the R-squared value drops to 60.01%, which still shows a reasonably strong relationship between cohesion and dry density.

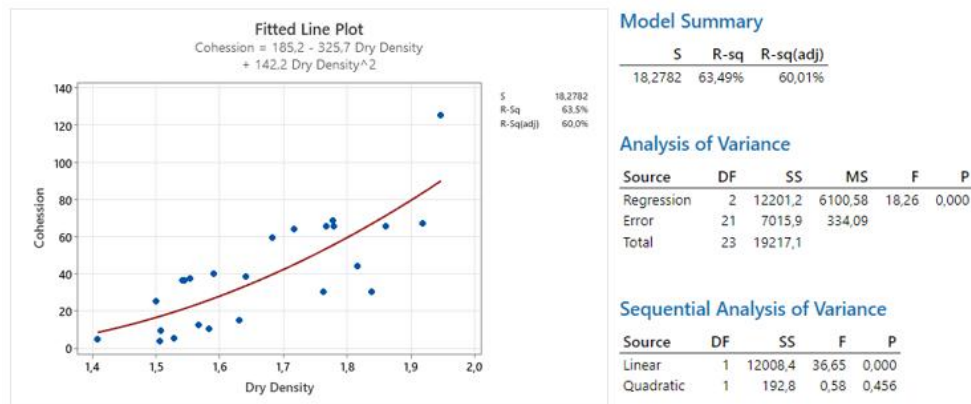


Figure 7. Regression analysis result of dry density vs cohesion

The analysis of variance shows that the overall model is significant, with an F value of 18.26 and a P value of 0.000. This value means that the model is statistically sound in describing the relationship between its variables. However, the standard deviation of the residuals of 18.2782 indicates a considerable deviation between the model's predicted results and the actual data, indicating that the model still has limitations in predicting with high accuracy.

The regression analysis between the internal friction angle variable from the direct shear test and dry density has an R-squared value of 60.32%, indicating a relatively strong relationship. The adjusted R-squared value of 56.54% provides a more conservative measure of model accuracy (Figure IV.7). Nonetheless, about 39.68% of the variation in the data is influenced by other factors such as cohesion value, material composition, and others. The standard deviation

of the residuals of 5.00365 indicates that the degree of deviation of the predictions from the actual values is relatively small. Thus, the model has moderate prediction accuracy.

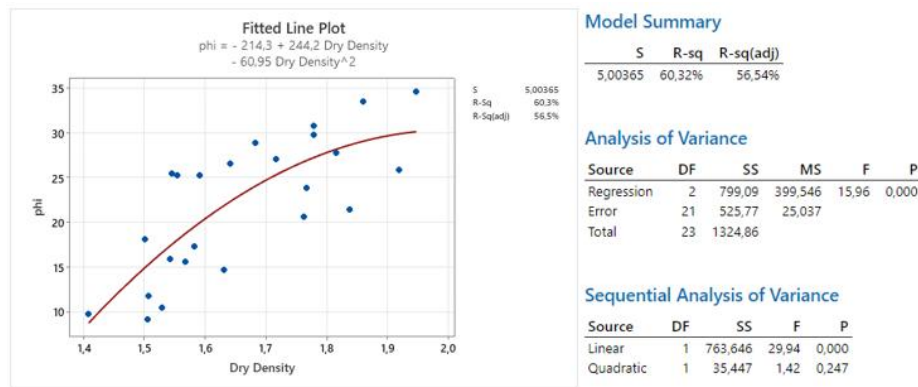


Figure 8. Regression analysis result of dry density vs cohesion

The results of the ANOVA analysis showed that the overall regression model was significant, with an F value of 15.96 and P of 0.000, indicating a real relationship between phi and Dry Density. Most of the variation in the data could be explained by the model, especially by the statistically significant linear component (F = 29.94, P = 0.000). In contrast, the quadratic component was insignificant (F = 1.42, P = 0.247), indicating that adding a quadratic relationship did not explain the variation in the data. Although this model explained 60.32% of the total variation in the data, the remaining variation indicates that other factors beyond Dry Density affect internal friction angle.

One factor affecting the compaction of the material is the consolidation process. Consolidation is a change in the volume of the waste dump due to normal forces in the waste dump body. The consolidation process resulted in an increasing density of material. This process is influenced by the type of material, load, time, and water content in the waste dump material. Naturally, the waste dump material will experience an increase in density over time due to the consolidation process. The waste dump material will be consolidated when it reaches its critical height. The critical dump height of the material can be calculated as follows:

$$H_{cr} = \frac{C_u^{design} \cdot N_C}{\gamma_{dump}} \quad (IV.1)$$

where:

- H_{cr} : Critical dump height, which is the maximum safe dump height before shear failure occurs (consolidation process)
- C_u^{design} : Soil shear strength (undrained shear strength) used in the design (kN/m²)
- N_C : Bearing capacity factor, usually dependent on shear conditions
- γ_{dump} : Unit weight of the material (kN/m³)

After the material experiences the consolidation process from the load, the consolidation rate is determined by time and water content. The material consolidation rate over time can be calculated through equations as follows:

$$t = \frac{H_d^2 \cdot T_v}{C_v} \quad (IV.2)$$

$$T_v = \frac{\pi}{4} \left(\frac{U\%}{100} \right)^2 \quad (IV.3)$$

where:

- t : Consolidation time (t is usually expressed in time units such as days or years)
- H_d^2 : Thickness of the effective drainage layer (in meters)
- T_v : Consolidation time factor
- C_v : Soil consolidation coefficient (m^2/t)
- $U\%$: Desired degree of consolidation (in percent, e.g., 90%)

Ismail (2020) studied the consolidation process in the waste dump material in the research area in the article "Evaluasi karakteristik kekuatan material pada formasi batuan sedimen Warukin, Kalimantan Selatan". This study shows the predicted consolidation value of the waste dump material in the study area and the actual data based on the drilling results, as shown in Figure 9.

The calculation results show that the time required to achieve maximum consolidation (95%) is above 20 months. In one year, consolidation occurs at only about 70%. The drilling results show that the strength of the waste dump material was increased in the 24-month-old waste dump. Under these conditions, it is estimated that the material has experienced maximum consolidation and compaction.

Referring to the results of laboratory and field tests, increasing the compaction value of materials by relying on consolidation time takes a long time. In the mining sequence in the study area, with a significant production rate and limited area, waiting for the material natural consolidation time cannot be done because it can delay mining operations. Therefore, another treatment is needed to increase the density value of the waste dump so that the waste dump capacity can be achieved according to the target plan.

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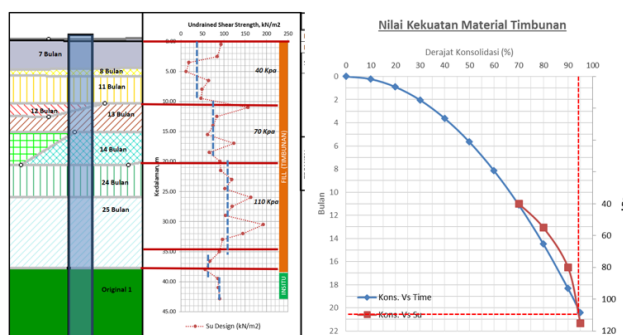


Figure 9. Correlation of consolidation and time in waste dump material of Warukin Formation (Ismail et al, 2020)

Field Trial of New Dumping Method

The trial was tested using Design of Experiment with Minitab software using Multilevel Factorial Design. Experiments were carried out with 3 factors (Figure 10), which are the difference in compaction equipment, the number of passes, and the depth of density sampling.

Design Summary

Factors:	3	Replicates:	1
Base runs:	24	Total runs:	24
Base blocks:	1	Total blocks:	1

Number of levels: 2; 3; 4

Figure 10. Design summary of the field trial

The increase in density value was carried out in two stages, the first being a change in the height of the backfill layer from the previous five meters to two meters (Figure 11). The two-meter figure was chosen because it is the minimum layer thickness required for an operational waste dump. Dumping below two meters will complicate waste dump operations, and dumping above two meters will cause not all materials to be compacted.



Figure 11. Construction of two-meters layer of waste dump

The second stage is loading during dumping. The waste dump material is expected to compact by applying a load during dumping. In the load test, conventional compaction was carried out using a 20-ton compactor (the largest compactor available on site at the moment) with several passing variables to see the level of influence (Figure 12.a). In addition, the test also measured compaction caused by heavy dump truck traffic (Figure 12.b). This was done to determine the effect of changes in material density when passed by a heavy dump truck with a capacity of 100 tons.



Figure 12. (a) Compaction test with Compactor Cat CS79 and (b) Compaction test with heavy dump truck HD Cat 777

After field testing, undisturbed samples were taken to test the density value (Figure IV.13). Sample testing was carried out in an internal laboratory so that the condition of the material was not much disturbed. In each test, four samples were taken to represent each depth of material.



Figure 13 (a) Field testing sampling and (b) sample testing in the laboratory

The results of compaction testing using a 20-ton compactor on a two-meter waste dump layer showed an increase in density values as the number of passes of the Cat CS79B compactor increased. In the initial condition before compaction or when the material was just pushed using a dozer, the density value of the material was 1.48 g/cm^3 or 80.84%. When compaction is performed using a Cat CS79B compactor, there is an increase in density value, as shown in Figure 14.

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StdOrder	RunOrder	PtType	Blocks	Equipment	Number of Pass	Depth	Density Result
1	3	1	1	1 HD Cat 777	10	1,5	1,50
2	17	2	1	1 Compactor Cat CS79B	20	0,5	1,67
3	5	3	1	1 HD Cat 777	20	0,5	1,67
4	20	4	1	1 Compactor Cat CS79B	20	2,0	1,70
5	8	5	1	1 HD Cat 777	20	2,0	1,54
6	16	6	1	1 Compactor Cat CS79B	10	2,0	1,62
7	23	7	1	1 Compactor Cat CS79B	30	1,5	1,81
8	4	8	1	1 HD Cat 777	10	2,0	1,53
9	21	9	1	1 Compactor Cat CS79B	30	0,5	1,60
10	13	10	1	1 Compactor Cat CS79B	10	0,5	1,57
11	2	11	1	1 HD Cat 777	10	1,0	1,44
12	12	12	1	1 HD Cat 777	30	2,0	1,61
13	1	13	1	1 HD Cat 777	10	0,5	1,53
14	10	14	1	1 HD Cat 777	30	1,0	1,76
15	18	15	1	1 Compactor Cat CS79B	20	1,0	1,71
16	15	16	1	1 Compactor Cat CS79B	10	1,5	1,56
17	24	17	1	1 Compactor Cat CS79B	30	2,0	1,73
18	7	18	1	1 HD Cat 777	20	1,5	1,61
19	22	19	1	1 Compactor Cat CS79B	30	1,0	1,68
20	9	20	1	1 HD Cat 777	30	0,5	1,72
21	14	21	1	1 Compactor Cat CS79B	10	1,0	1,69
22	11	22	1	1 HD Cat 777	30	1,5	1,62
23	19	23	1	1 Compactor Cat CS79B	20	1,5	1,72
24	6	24	1	1 HD Cat 777	20	1,0	1,63

Figure 14. Trial results of compaction testing inputted in minitab software

The results of the analysis of variance of the factorial design (Figure 15) show that the model has a p-value of 0.005, which means that the tested factors have a significant influence on the density results of the disposal material. The equipment factor or compactor used in the experiment has a p-value of 0.011, which explains that the difference in compactor between HD Cat 777 and Compactor Cat CS798 also contributes to the change in material density value. The number of passes with a p-value of 0.002 shows it as the most influential factor on density change. In the experimental results, the change in depth in the range of 0.5m to 2m did not show a significant effect on the variation of density change with a p-value of 0.857.

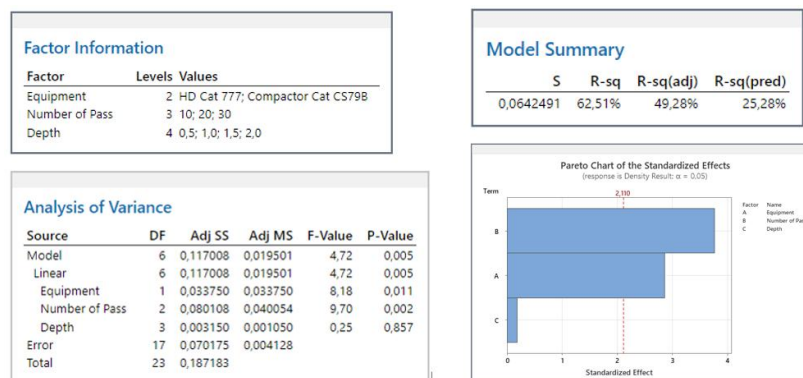


Figure 15. Design of Experiment Analysis Result

The coefficient of determination from the model generated in Minitab shows an R-squared value of 62.51%. This shows that the variation in density results can be explained by the model but there are still other influential factors that are not included in this model such as material composition and water content. R-squared (adj) is the coefficient of determination that has been modified by considering the number of predictors or factors in the regression equation in the model. The R-squared (adj) value in the model shows a value of 49.28% or lower, but still shows a good explanation of variability.

The results of the level of influence factors in the experiment can be seen in the Pareto chart. The number of passes is the most influential factor in the experiment, followed by the type of equipment. While the depth factor has no significant effect, so the compaction every two meters still has the impact of compaction.

From the results of field testing with the two compaction methods, the same pattern is obtained: the increase in density values as the number of passes increases. The target density value is obtained at the number of compactor passes of 20 passes and 30 passes, while if using Heavy Dump Truck traffic, the target density value is also obtained at 30 passes, although with a smaller density value. The pattern of increasing density values can be seen in Figure 16.

The capability results of the compaction process using the Compactor and Heavy Dump Truck at the number of passes of 20 passes and 30 passes showed an increase in material density results, with average results closer to the target, smaller variations, and a reduced number of density values below the minimum limit (Figure 17). The compaction process increased the sigma level from 1.88 to 2.50.

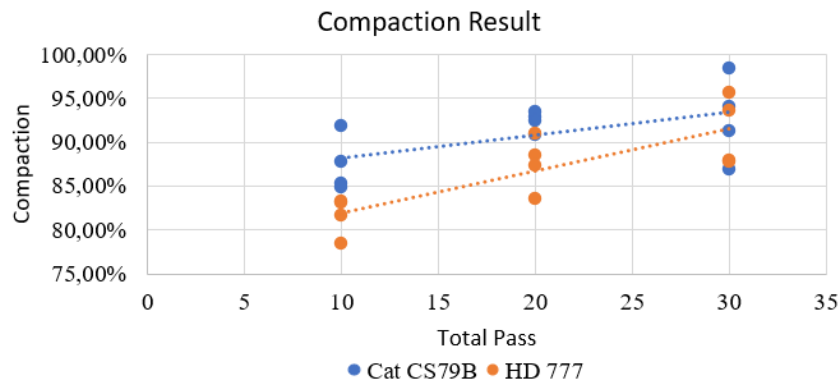


Figure 16. Correlation of compaction result and total pass.

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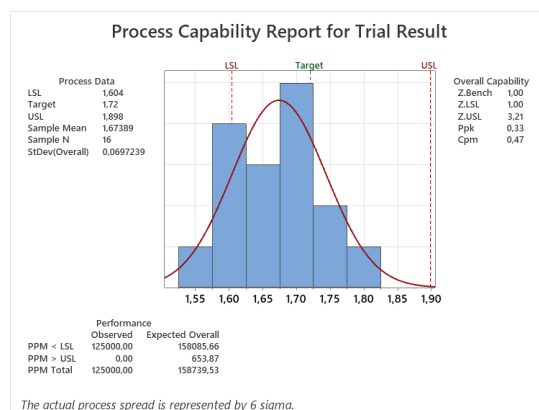


Figure 17. Capability analysis result of dry density for trial result

Geotechnical Simulation

As the density value increases, further processing of waste dump material strength as a geotechnical simulation parameter was carried out. Updating the material strength parameters is conducted by eliminating the results of laboratory tests on waste dump materials with density values outside the lower limit. The difference in material strength values can be seen in Table 1.

Table 1. Change in material strength value based on compaction value

Material	qu (kPa)		C (kPa)		Phi (°)	
	Average	Std Deviation	Average	Std Deviation	Average	Std Deviation
All Compaction	201.10	182.56	34.98	21.94	21.28	7.20
Compaction 85%<	251.34	179.32	47.02	17.84	24.60	5.03

Geotechnical analysis was conducted with changes in the strength parameter values of the waste dump material. The strength of the new dump material has increased in terms of cohesion and internal friction angle (phi). The increase in material strength will increase the FS (factor of safety) value of the same design, so design optimization is carried out until the FS value is the same or in accordance with safety standards. The Geotechnical analysis was carried out using Finite Element Software RS2 by Rocscience.

Sample area of the waste dump was used in this research to represent the additional volume capacity. The design used was the Inpit Dump Design (IPD) in the research area, with the waste dump design has an overall slope angle (OSA) of 6.0° and a total height of 65 meters. The basement of the IPD design has a slope of 3° to 5°. Simulation of the stability of the initial waste dump design was carried out under 2 conditions, using the value of material strength properties with normal dumping and compaction method. The simulation results showed a change in the Factor of safety value, the initial design with normal dumping method had an FK value of 1.30 (Figure 18.a) and the initial design with compaction method had an FK value of 1.37 (Figure 18.b)

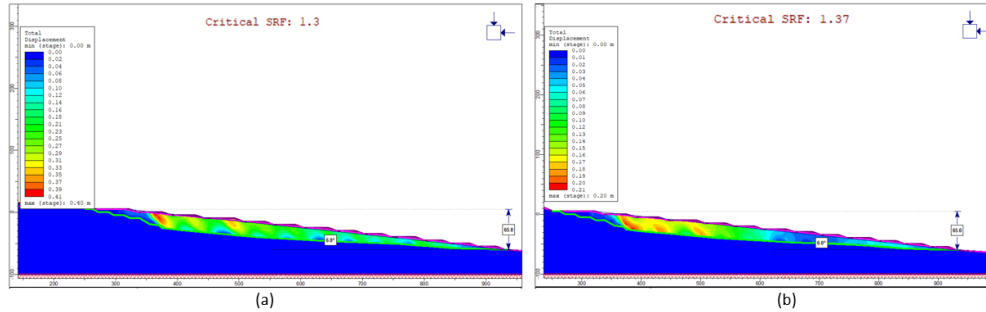


Figure 18. Initial design stability simulation results. (a) with normal dumping material strength and (b) with compaction material strength

To increase the disposal capacity, the waste dump design optimization was carried out with the target FK value close to the initial design condition under normal dumping conditions. The waste dump design optimization was carried out by enforcing the design OSA to 7.5°. The new design has an FK value of 1.32 (Figure 19).

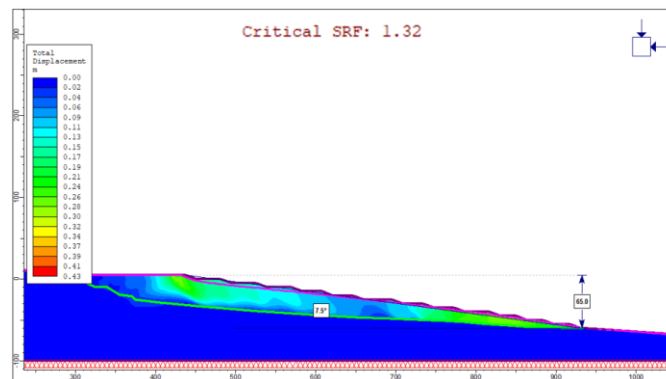


Figure 19. Stability simulation results of optimization design using material strength of compaction method

CONCLUSION

Based on the regression analysis of existing waste dump material sample, the higher compaction number contributes to an increase in the strength of the material, which is indicated by higher UCS, cohesion, and inner friction angle values. In the field trial result, reduction of the dumping layer height from 5 meters to 2 meters and compaction treatment with a compactor and heavy dump truck significantly improved the compaction level of the waste dump material in the research area. The capability results of the compaction process using the Compactor and Heavy Dump Truck at the number of passes of 20 passes and 30 passes showed an increase in material density results, with average results closer to the target, smaller variations, and a reduced number of density values below the minimum limit.

Increased material strength due to higher compaction enabled the design of a steeper and more stable waste dump geometry. In the research area, the in pit dump design has an increased

of Factor of Safety from 1.30 to 1.37. Therefore, the design can be re-optimized to increase the waste dump capacity. The optimization design was carried out by increasing the overall slope angle from 6° to 7.5°. The optimized design has a factor of safety of 1.32. In the case study, there is an increase in disposal capacity from 5,444,097 BCM to 7,249,037 BCM.

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