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The Effects of Compaction Towards Diversion Channel Base Material

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ABSTRACT

The sustainability and safety of surface mine operations often depend on various factors, including the hydrology of the area and a suitable plan to address its challenges. Some of the concerns related to hydrological issues include the drainage system and its design preparation. In special cases where river diversion is required, there may be specific issues with the planning and construction process. In such instances, a diversion channel is planned to be built between two closely situated pits. This channel will be constructed upon an embankment consisting of disposal materials. The plan has implications for the spatial positioning and the choice of materials for the channel base. The embankment requires proper treatment and processes during its construction, such as compaction and consolidation. This study addresses the effectiveness of compaction efforts on the material's capacity concerning its physical, mechanical, and hydrogeological properties. The analysis was conducted using correlations between laboratory test results and extracted hydrogeological data using software instrumentation. These correlations specifically examine the changes in compaction values in relation to changes in material properties. The study concludes that compaction efforts have a significant impact on the material's ability to support the diversion channel, making it an effective means of enhancing the material's capabilities

INTRODUCTION

Hydrology in one of many aspects should be considered and be dealt with in open main operation. The sustainability of mine operation often depends on hydrology engineering to contain and direct surface water from though out the mining area using proper mine drainage systems. One of them is the requirements of a specific channel for diverting body of water to where it is not disrupting the mine operation while it is still safe for the environment.

River diversion has been studied by various researchers and is known in various terms such as watercourse diversion (DNRM, 2015), inter-basin water transfer (Shao & Wang, 2003), river realignment (Erskine, 1992), channelization (Soar & Thorne, 2011), water diversion (Yevjevich, 2001), river deviation

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(McEwan, 1999), and river flow control works (Austlii, 2019), river relocation or river diversion (Flatley, et al., 2018). However, not many have studied the physical, mechanical, and hydrogeological aspects of the channel bed in the form of embankment material itself.

The study area required a diversion channel, which was proposed to be built on an embankment between two closely situated active pits. The embankment itself would consist of an existing consolidated embankment that is older than 5 years, while the channel base would be constructed using new disposal material.

Disposal material is overburden material excavated from the pit to obtain mining objects. The volume of this material tends to expand after being unloaded compared to in situ material because it is loose (Mulyanti et al., 2017). Given that the disposal material is loose, the stockpile material tends to be loose and has high porosity and hydraulic conductivity. Moreover, for the embankment body, which is not compacted and has interconnected cavities, the hydraulic conductivity of the material is higher. When the channel is placed on the embankment material, it allows water to flow, reducing the strength of the material (Supandi et al., 2013, 2018, 2019). The interaction of water with the material has the potential to cause stability disturbances in the disposal heap and affect security in the vicinity of the embankment (Supandi et al., 2016). A higher groundwater level in the material can lead to instability, and vice versa (Riyadi, 2013).

The study aimed to examine how compaction affects the material condition related to the use of embankment material as the base for an open channel. It will investigate the physical, mechanical, and hydrogeological properties of the material due to compaction efforts. Therefore, it seeks to provide information regarding the effectiveness of compaction in enhancing the suitability of embankment material for use as channel bed material. The study will answer whether compaction was effective in maintaining the channel's integrity in the hydrogeological conditions of the embankment material and how this process worked.

METHODOLOGY

Compaction and Consolidation

The terms compaction and consolidation are often mistakenly used interchangeably, but there are conceptual differences between the two processes. Compaction is the process of increasing the density of soil or material by compressing its particles and reducing the volume of air without significantly reducing the volume of water within the material. In contrast, consolidation is the reduction of water volume in saturated soil or material, characterized by low conductivity, due to the dissipation of pore water pressure. This process continues until the excess pore water pressure, which increases due to loading-induced stress, is completely dissipated (Craig, 2004).

Compaction is an artificial process that involves using tools and methods to reduce the air in the voids of the soil or material. Consolidation, on the other hand, is a natural process that gradually reduces the water volume in the material as pore water pressure is released over time. Another distinguishing factor between compaction and consolidation is their relationship with time. Compaction is not significantly time-dependent, whereas consolidation is highly time-dependent and the duration plays a crucial role in completing the consolidation process (Bolarinwa et al., 2017).

In civil engineering, the term consolidation is used in the same sense as the physical process of gravitational compaction (Greensmith & Tucker, 1986). Consolidation is defined as the slow outflow of fluid from the pores and the reduction of voids within the material body due to the pressure from overburden (Greensmith & Tucker, 1986). To summarize the key differences between compaction and consolidation, refer to **Table 1** based on the above references.

Tabel 1. Key difference between compaction and consolidation

No	Column Header Goes Here	Column Header Goes Here
1	The load is applied mechanically to compress the material, with the aim of increasing the strength of the material.	Loading occurs continuously with a constant (static) load, causing compression of the saturated material.
2	Loading in the form of dynamic loads with mechanical methods such as tamping, rolling, and vibration in a relatively short time interval.	Static loading occurs continuously for a long time.
3	The volume of the material is reduced by removing air from the saturated or dry material.	The volume of the material is reduced due to the exit of pore water from the saturated material.
4	The load is applied mechanically to compress the material, with the aim of increasing the strength of the material.	Loading occurs continuously with a constant (static) load, causing compression of the saturated material.
5	Loading in the form of dynamic loads with mechanical methods such as tamping, rolling, and vibration in a relatively short time interval.	Static loading occurs continuously for a long time.

Hydraulic Conductivity

The hydraulic conductivity of a material is a main factor in hydrogeology that significantly influences strategic decision-making (Riyadi et al., 2019). Several factors affect the hydraulic conductivity system, including rock mass characteristics such as fracture areas, depth, mineral content within fractures, and lithology (Hsu et al., 2011; Iskandar & Koike, 2011; Cahyadi, 2018). Hydraulic complexity can impact water flow in fractured media, making it more challenging to estimate hydraulic conductivity values (Cahyadi et al., 2017). As depth increases, conductivity values tend to decrease due to the reduction in fracture spacing caused by geostatic stresses (Cahyadi, 2018). Depth also plays a significant role in determining conductivity values (Hsu et al., 2011). In general, materials at shallower depths exhibit higher conductivity values. Gouge content refers to the presence of filling material, typically clay or quartz, within rock fractures. Fractures rich in fillings generally exhibit very low conductivity (Hsu et al., 2011).

Relationship to Hydraulic Conductivity Value

Material parameters and their correlation with hydraulic conductivity can be determined through a non-linear equation represented by the groundwater characteristic relationship curve. This equation is based on the assumption that the water characteristic curve's shape is influenced by the soil's pore size distribution, as proposed by Fredlund and Xing in 1994.

After a review of various empirical, macroscopic, and statistical models (Leong & Rahardjo, 1997), the model's equation is as follows:

$$K = K_s \cdot \frac{1}{\left(\ln\left(e+\left(\frac{\varphi}{A}\right)^B\right)\right)^C} \quad \text{.............................} (1)$$

Ks represents the saturated hydraulic conductivity, while *K* is the hydraulic conductivity. The parameter 'e' represents the exponential number (approximately 2.7182818), and 'matric suction' characterizes the material. A, B, and C are correction factors that describe the material's characteristics. The coefficients for A, B, and C can be found in **Table 2.**

Tabel 2. Coefficient A, B, and C (Leong & Rahardjo, 1997)

Material	A	B	C
Beit Netofa Clay	6746	0,55	201,1
Rehovot Sand	2,65	3,86	8,37
Touchet Silt Loam	8,55	13,07	1,96
Columbia Sandy Lome	6,37	12,9	2,24
Supersition Sand	3,07	6,19	3,93
Yolo Light Clay	3,39	1,204	6,06
Mine Tailings - Wetting	18,28	2,51	7,49
Mine Tailings- Drying	19,21	4,82	4,49

Material Strength

The concepts of rock strength refers to the Mohr-Couloumb concepts (RocScience, 2010). Rock strength (τ) is expressed as a parameter consisting of cohesion components (c), normal stresses (σ_n) derived from rock density, pore pressure (u), and internal friction angle (ϕ). Rock strength is expressed in the following equation:

$$\tau = c' + (\sigma_n - u)\ tan\ \ \phi' \text{ .... (2)}$$

$$\sigma_n = W.\cos\alpha \text{ .... (3)}$$

The study was conducted using laboratory data for the disposal material used in building an embankment with a diversion channel built on top. The analysis included correlations between laboratory data and values extracted from calculations using RocScience: Slide 6 software, which assesses its hydrogeological capabilities. This analysis aimed to investigate the effect of compaction efforts on hydrogeological properties.

RESULT

Laboratory Test Results

Laboratory tests are necessary to obtain the parameters required for conducting slope stability analysis, specifically the physical and mechanical properties of the materials. These laboratory tests aim to acquire physical and geomechanical parameters. In this study, the chosen method for slope stability analysis is the limit equilibrium method, utilizing the Mohr-Coulomb concept of rock strength. In this concept, the cohesion and internal shear angle are the primary factors influencing slope stability analysis. Due to the need for cohesion and the internal friction angle, the scope of the laboratory analysis work includes tri-axial tests. The selection of the tri-axial method yields more optimal results compared to the direct shear test method, as the latter enforces the shearing process in a plane with vertical loading (stress).

The triaxial method accounts for stress conditions that work in both vertical and horizontal directions, representing the resultant of three different stress axes. Disposal material samples were collected from the surface of the embankment slopes, while in-situ material test samples consist of rock core samples obtained through rock core drilling. PT. Indra Karya Persero in Malang, East Java, Indonesia, conducted the laboratory testing and holds competence and certification in this field.

Physical Properties

The testing of material properties for the disposal stockpile was conducted under the assumption that the stockpile materials on-site had been consolidated for over 5 years. Subsequently, the consolidated embankment material would be dismantled to create a channel. In specific areas, voids were identified, necessitating the use of material from the demolished embankment to fill them. Compaction tests were performed to determine the material's density under optimum conditions, which involved assessing the embankment material's density and water content. The combination of solids and water content at a certain point would reach the peak compaction level. If any of these values are exceeded after reaching the peak condition, compaction will decrease.

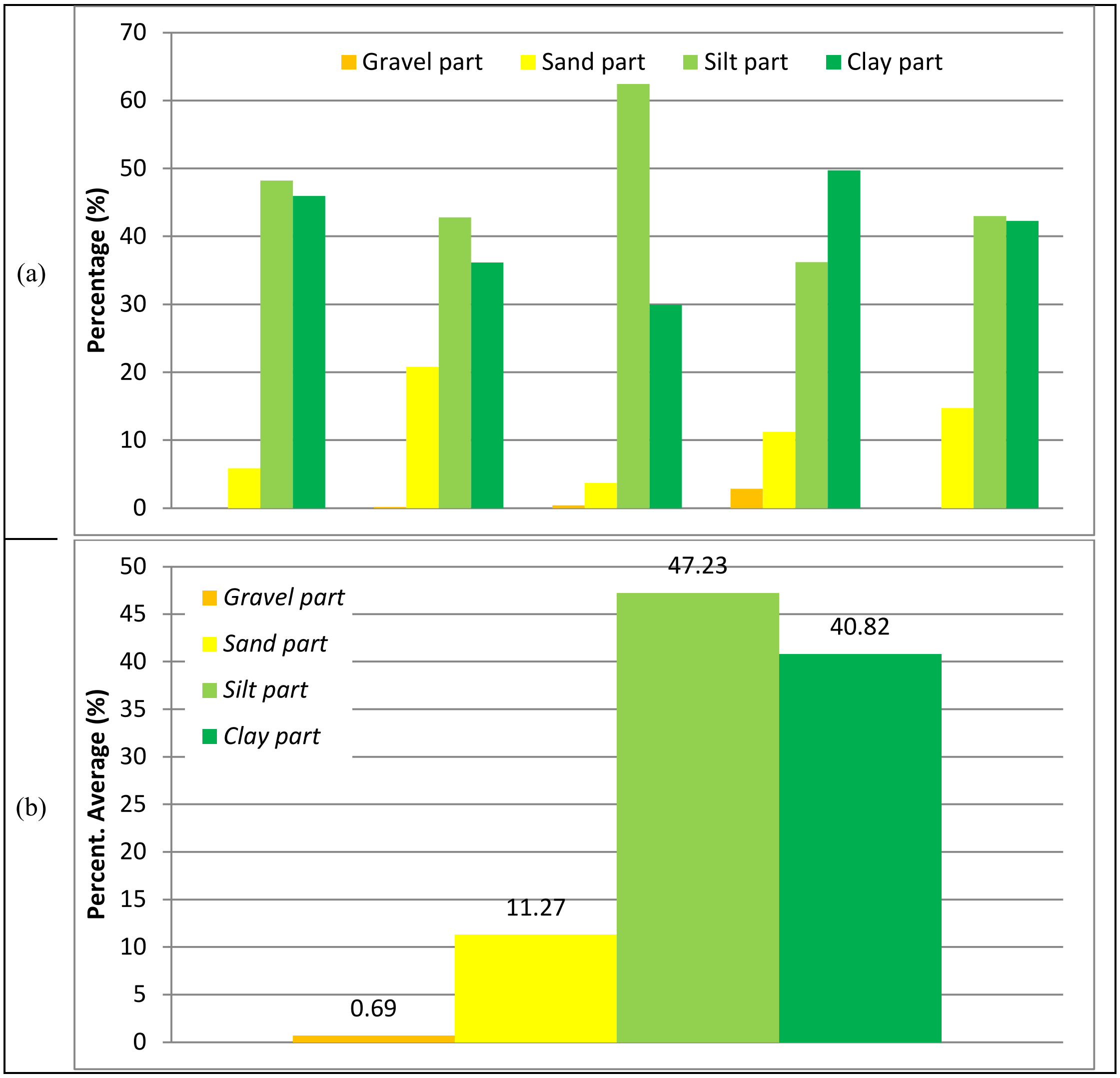

Figure 1. (a) Percentage of grain size of the embankment material sample. (b) Percentage of the average grain size of the same embankment material

The grain size test measurements show that the weathered and consolidated disposal heap material at the study site has an average grain size dominated by 47.23% silt, 40.82% clay, and 11.27% sand, with a minor component of 0.69% gravel. Based on the results of the grain size test, the data follows a normal distribution, with all data falling within one standard deviation from the average value ($\mu \pm \sigma$).

(a)

(b)

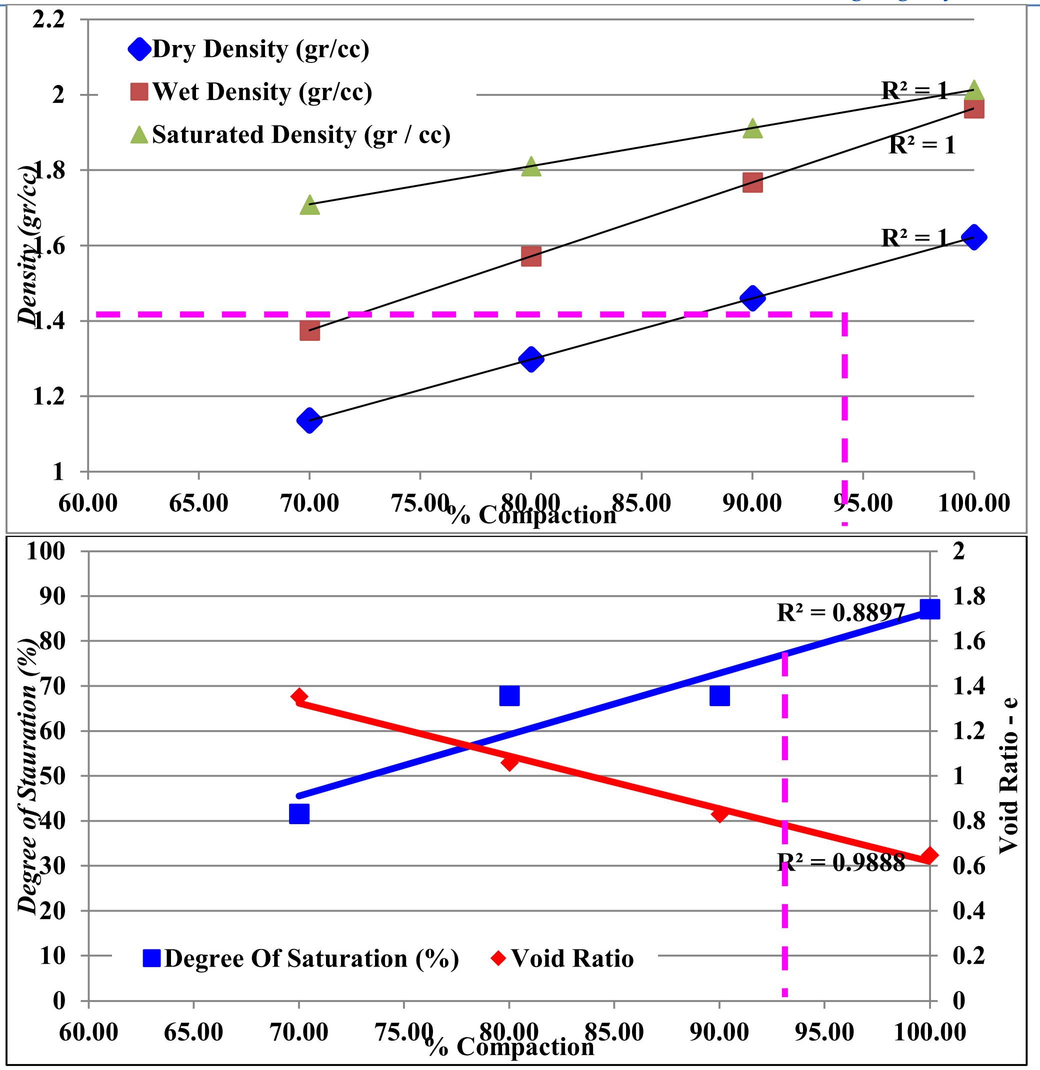

Figure 2. (a) Correlations of percent compaction to material densities. (b) Correlation of degree of saturation and void ratio to percent compaction

The compaction parameter is specified in terms of percent compaction. Percent compaction refers to the dry density of the material expressed as a percentage of its maximum possible density, achieved at a specific moisture content. The material is considered to be at maximum compaction when it reaches 100% compaction. This ideal condition can be attained under controlled laboratory conditions, where both moisture content and density can be precisely regulated. In real-world field conditions, achieving 100% maximum compaction requires the careful management of compaction efforts and consolidation time, which can be challenging to control. The compaction value was determined by simulating various compaction conditions, including 70%, 80%, 90%, and 100%. The consolidated embankment material found in existing embankments in the field exhibited a compaction value of 93%. This determination was based on a comparison of density values, degree of saturation, void ratio, and water content. The suitability of this value also validates the correlation curves established between percent compaction and material properties.

Plotting was conducted using the values of properties and the percentage of compaction to illustrate the relationship between the properties of the embankment material at various compaction states. The plotted values represent the average results from each of the 5 samples for each laboratory test. The laboratory test results for the embankment material follow a normal distribution, with the requirement that all data falls within the range of 2 times the standard deviation ($\mu \pm 2\sigma$) for each point when testing physical and mechanical properties.

The main physical property of a material is its density, which consists of values representing dry, wet, and saturated conditions, respectively. A more compact material should have a higher density. The correlation between density values and percent compaction is shown in **Figure 2a.** Density values increase with the increase in percent compaction..

Compaction of embankment material serves to compress the material. Materials with a higher percent compaction will have a smaller void ratio as the pores in the material become smaller due to compression, making the material denser. As the voids decrease, the density of the material increases. Denser materials have fewer voids or pores in the mass, and the water content is also reduced. Meanwhile, saturation increases due to the decreasing void ratio as it approaches the solid state. The correlation between void ratio values and degree of saturation values with percent compaction is shown in **Figure 2b**. Additionally, the correlation between water content and percent compaction is shown in **Figure 3**.

Based on the physical property tests, it can be concluded that as the material's percent compaction increases, its density also increases (**Figure 2a**). This is supported by the decrease in void ratio as percent compaction increases (**Figure 2b**). The increase in density is a result of the reduction in voids within the material, leading to an increase in mass per unit volume. As percent compaction increases, the water content decreases, but the degree of saturation increases. This indicates that the storage capacity of denser materials decreases (saturation occurs more rapidly) in line with the increase in percent compaction..

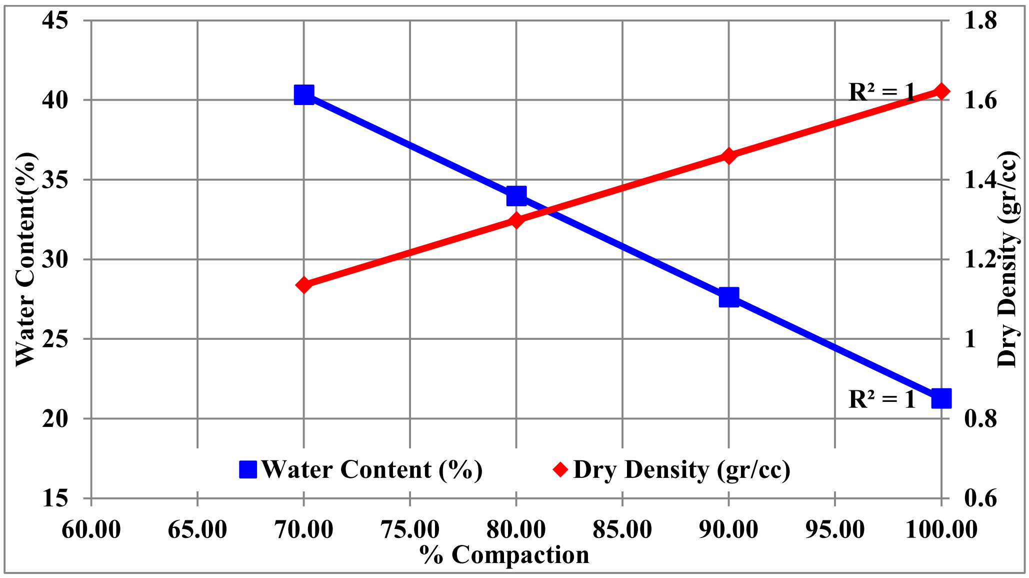

Figure 3. Correlations of water content and dry density to percent compaction

Mechanical Properties

Laboratory tests were conducted to evaluate the mechanical properties of the material, employing tri-axial tests to determine both cohesion and internal friction angles at compaction levels of 80%, 90%, and 100%. The average values of these properties were then graphed against the degree of compaction to understand the relationship between compaction and material properties, as depicted in Figure 4. Materials subjected to higher compaction ratios exhibited greater cohesion and internal friction angles, highlighting that compaction not only optimizes physical properties but also enhances mechanical properties.

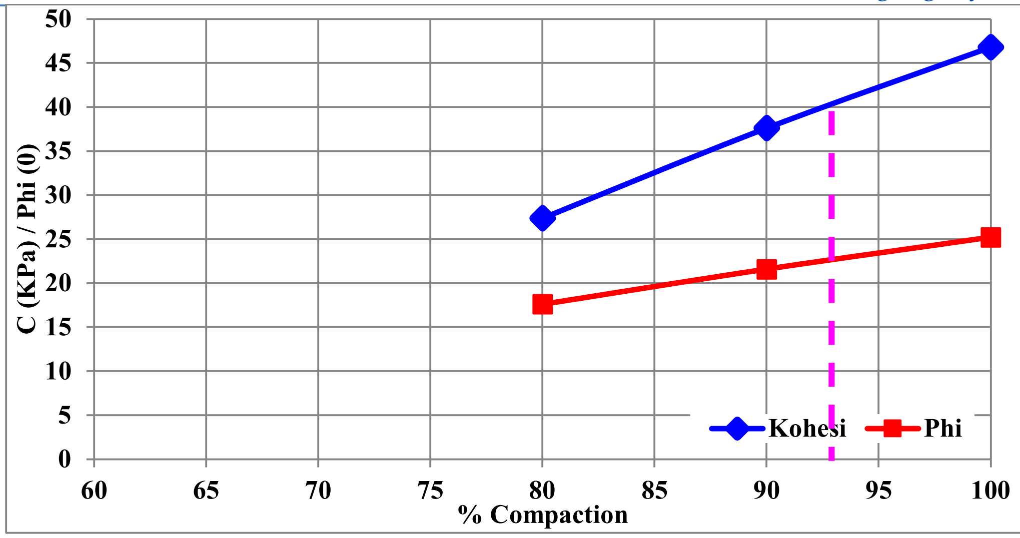

Figure 4. Correlation of cohesion value and internal friction angle (ϕ) to the value of percent compaction

Effect of Compaction toward Hydraulic Properties

Change in Matric Suction

To understand the changes in hydraulic properties due to compaction, an analysis was performed on groundwater parameters using RocScience: Slide 6 software instrumentation. Different values of water content were considered based on the hydraulic parameter model by Fredlund and Xing (1994) and Leong and Rahardjo (1997) for material criteria in mine tailings, specifically the wetting condition. The matric suction value was extracted and correlated with its respective water content variable. The correlation of matric suction to water content is illustrated in **Figure 5a**. The analysis reveals that matric suction tends to decrease as the water content of the material increases. Furthermore, the relationship between water content at each percent compaction and matric suction is depicted in **Figure 5a**. The value of matric suction can be correlated with the degree of percent compaction, as shown in **Figure 5b**. This figure demonstrates how the moisture content and matric suction of the embankment material change with varying percent compaction. It becomes apparent that increasing compaction results in reduced water content due to decreasing porosity.

Compaction Relationship with Hydraulic Conductivity

The calculation of hydraulic conductivity values was performed under various compaction conditions (ranging from 70% to 100%) to determine the ratio of conductivity in the presence of compaction. These calculations were based on Equation (1). The coefficient values A, B, and C, specific to the embankment material in this study, were selected for "Mine Tailings - Wetting," as listed in **Table 2**. These criteria were determined for materials in their initial dry state undergoing a wetting process. The values of water content and matric suction at a specific compaction level can be obtained from **Figure 5b**.

Figure 6 illustrates the relationship between hydraulic conductivity values, calculated based on percent compaction, and moisture content. As the water content in the material decreases, the matric suction increases. This increase in matric suction, induced by reduced water content, leads to a decrease in the hydraulic conductivity of the material. Consequently, as the percent compaction increases, the hydraulic conductivity value decreases. This, in turn, regulates the amount of water flowing through the material. Thus, it is evident that compaction efforts can mitigate the impact of water flow within the channel, influencing the hydrogeological conditions of the embankment material.

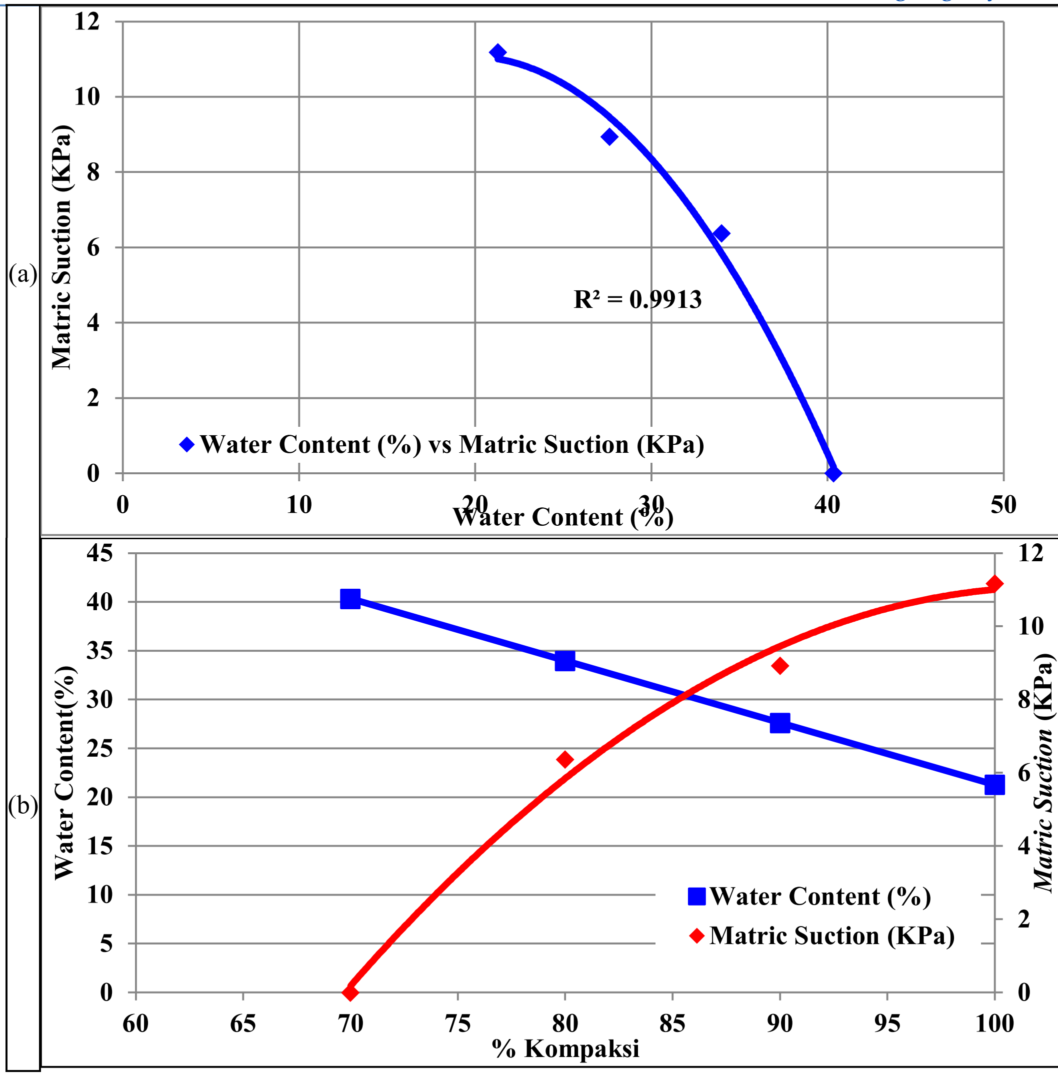

Figure 5. (a) Correlation of matric suction to water content. (b) Moisture content and matrix suction in each percent compaction.

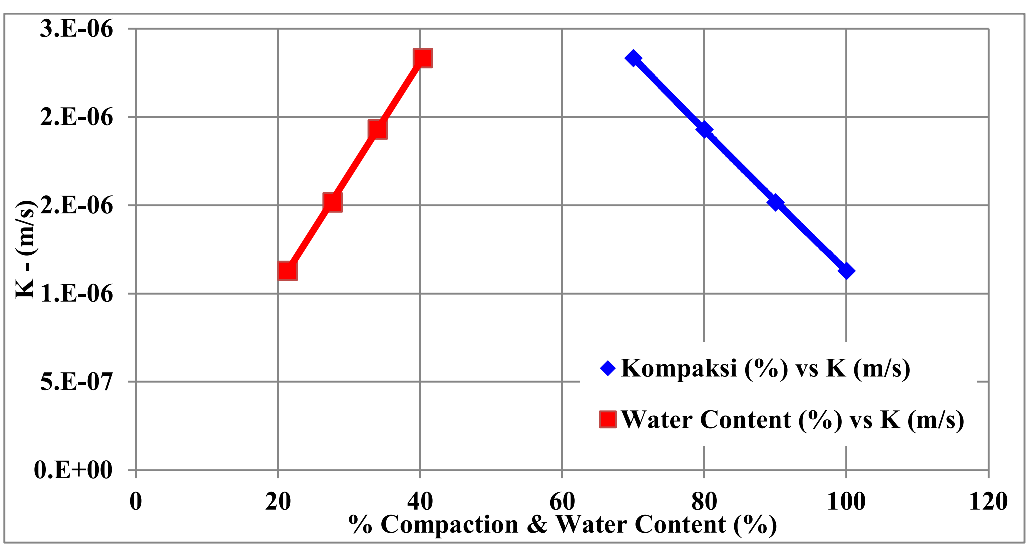

Figure 6. Correlation of hydraulic conductivity values to percent compaction and water content

CONCLUSION

Based on the results of the analysis of the laboratory test results of the embankment material, if compaction efforts were made, there will be changes in the characteristics of the material as follows:

a. Density will increase linearly with the increase in percent compaction. This is due to a reduction in voids within the material. The decrease in void ratio with increasing percent compaction causes the mass-to-volume ratio to increase.
b. The greater the percentage of compaction, the lower the water content becomes as the degree of saturation increases. This indicates that the storage capacity of the more compacted material has decreased, causing it to become saturated more quickly.
c. The hydraulic conductivity of the material decreases as saturation increases, due to a smaller void ratio and a denser material.

The higher the percent compaction, the lower the hydraulic conductivity value. A smaller hydraulic conductivity value will inhibit infiltration and water flow in the embankment material. Therefore, it was evident that compaction effort is effective for mitigating the impact of flow in the channel on the hydrogeological conditions of the embankment material.

REFERENCES

1. Austlii. (2019). Water Act. Dipetik September 26, 2018, dari Austlii: http://www.austlii.edu.au/cgibin/download.cgi/au/legis/cth/consol_act/wa200783
2. Bolarinwa, A., Adeyeri, J. B., & Okeke, T. C. (2017). Compaction and Consolidation Characteristics of Lateritic Soil of a Selected Site in Ikole Ekiti, Southwest Nigeria. Nigerian Journal of Technology (NIJOTECH), Vol. 36, No. 2, p. 339 –345.
3. Cahyadi, T. A. (2018). Pengembangan model Optimasi Desain Lubang Penyaliran Horizontal Tambang. Studi Kasus Tambang terbuka Grassberg PT. Freeport Indonesia. Disertasi, Institut Teknologi Bandung, Program Studi Doktor Rekayasa Pertambangan, Bandung.
4. Cahyadi, T. A., Widodo, L. E., Syihab, Z., Notosiswoyo, S., & Widijanto, E. (2017). Hydraulic Conductivity Modeling of Fractured Rock at Grasberg Surface Mine, Papua-Indonesia. J. Eng. Technol. Sci., Vol. 49, No. 1, p. 37 - 56.
5. Craig, R. F. (2004). Craig's Soil Mechanics (Seventh Edition ed.). Spon Press.
6. DNRM. (2015). Department of Natural Resources and Mines. Dipetik September 28, 2018, dari DNRM: http://www.dnrm.qld.gov.au/ __data/ assets/ pdf_file/ 0015/ 212424/ guideline-watercourse-diversions.pdf
7. Erskine, W. (1992). Channel Response to Large-scale Ricer Training Works: Hunter River, Australia. Regulation Rivers Resource Mining, 7, p. 261–278.
8. Flatley, A., Rutherford, I. D., & Hardie, R. (2018). River Channel Relocation: Problems and Prospects. Water, 10, p. 1360.
9. Fredlund, D., & Xing, A. (1994). Equations for The Soil-Water Characteristic Curve. Can. Geotecli. J., 31, p. 521-532.
10. Greensmith, J. T., & Tucker, E. V. (1986). Compaction and Consolidation. Dalam O. v. Plassche, Sea-Level Research (O. Plassche ed., hal. 591 - 592).
11. Hsu, S.-M., Lo, H.-C., Chi, S.-Y., & Ku, C.-Y. (2011). Rock Mass Hydraulic Conductivity Estimated by Two Empirical Model. Dalam O. Dikinya (Penyunt.), Developments in Hydraulic Conductivity Research (hal. 133 -158). InTech.
12. Iskandar, I., & Koike, A. (2011). Distinguishing Potential Sources of Arsenic Released to Groundwater Around a Fault zone Containing a Minesite. Environtmental Earth Science, 63, p. 595 - 608.
13. Leong, E. C., & Rahardjo, H. (1997). Permeability Function For Unsaturated Soil. J. Geotech. Geoenviron. Eng., 123(12), p. 1118-1126.

14. McEwan, A. (1999). The Failure of and Remedials to a River Diversion for an Opencast Mine in The Witbank Coalfields of South Africa. Mine Water and Environment (hal. 79–85). Sevilla, Spain: IMWA Congress.
15. Mulyanti, W. R., Yuliadi, & Maryanto. (2017). Analisa Teknis dan Ekonomis Strategi Short Distance Disposal West Block (Anoa South) Studi Kasus oleh Section Short Term Planning, Departemen Mines And Exploration Di PT Vale Indonesia, Tbk. Kecamatan Nuha, Kabupaten Luwu Timur. Prosiding Teknik Pertambangan. Vol. 1, No. 1, hal. 1-8. Bandung: UNISBA.
16. Riyadi, F. A. (2013). Geologi Dan Kajian Kestabilan Lereng Dengan Kontrol Muka Air Tanah Pada Lereng High Wall Pit Batulaki Utara, Kecamatan Satui, Kabupaten Tanah Bumbu, Provinsi Kalimantan Selatan. Studi Kasus Upaya Stabilisasi Lereng Dengan Pelandaian Lereng Dan Dewatering. Skripsi, Universitas Pembangunan Nasional "Veteran" Yogyakarta, Program Studi Teknik Geologi, Yogyakarta.
17. Riyadi, F. A., Cahyadi, T. A., Nurkhamim, & Supandi. (2019). Desain Saluran Terbuka Berbasis Microsoft Excel. Perhitungan dan Pemodelan yang Praktis dan Efisien. KURVATEK, h. 61-78.
18. Riyadi, F. A., Cahyadi, T. A., Nurkhamim, & Supandi. (2019). Model Fungsi Konduktifitas Hidrolik Terhadap Resistivitas Timbunan Disposal dan Material Insitu. PIT PAI. Bandung: PAAI.
19. Riyadi, F.A. (2019). Studi Hidrogeologi Untuk Penanggulangan Aliran Air Di Dalam Material Penyusun Alas Saluran. Tesis Magister Teknik Pertambangan, Universitas Pembangunan Nasional "Veteran" Yogyakarta.
20. Rocscience. (2010). Slide 6.0 Tutorials Manual. Dalam Rocscience, Slide 6.0 Tutorials Manual. Rocsscience.
21. Shao, X., & Wang, H. (2003). Interbasin transfer projects and their implications : A China case study. Intl. J. River Basin Management, 1, No. 1, p. 5–14.
22. Soar, P., & Thorne, C. (2011). Channel Restoration Design for Meandering Rivers. Vicksburg, MS, USA: U.S Army Corps of Engineers:
23. Supandi. (2013). Pemodelan Parameter Geoteknik dalam Merespon Perubahan Desain Tambang Batubara Dengan Sistem Tambang Terbuka. ReTTI, (hal. h. T1-T5). Yogyakarta.
24. Supandi, S., Riyadi, F. A., & Purnomo, S. (2016). Study Geolistrik Untuk Mengidentifikasi Kedudukan Lumpur dan Air Dalam Rangka Optimalisasi Timbunan Lowwall. ReTTI, p. 352-356.
25. Supandi, S., Zakaria, Z., Sukiyah, E., & Sudrajat, A. (2019). The Influence of Kaolinite- Illite Toward Mechanical Properties of Claystone. Open Geosci., 11, p. 440-446.
26. Supandi, Zakaria, Z., Sukiyah, E., & Sudradjat, A. (2018, December). The Correlation of Exposure Time And Claystone Properties At The Warukin Formation Indonesia. International Journal of GEOMATE, 15(52), p. 160-167.
27. Yevjevich, V. (2001). Water diversions and Interbasin Transfers. Water International, 26, p. 342–348.