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GEOMETRY ASSESSMENT ON THE SLOPE STABILITY OF MANYAR POND

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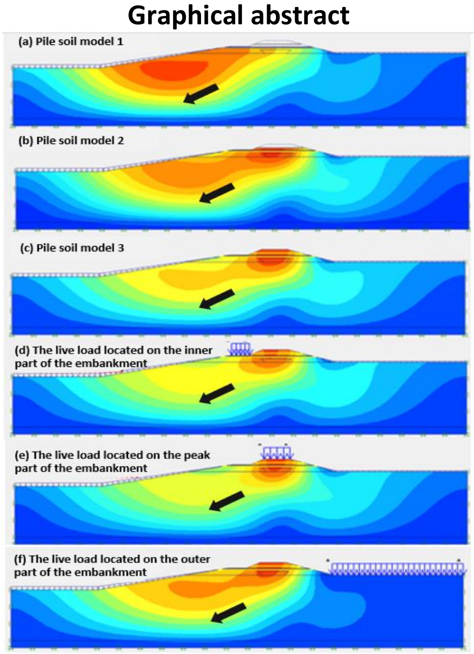
Graphical abstract



Abstract

Lateritic soil was treated with 0%, 4%, 8%, 12%, and 16% Rice Husk Ash (RHA) by dry soil weight to determine its consolidation properties. Test carried out include particle size distribution, specific gravity, compaction test with varying compactive efforts (British Standard Light (BSL), West African Standard (WAS) as well as British Standard Heavy (BSH)) and consolidation test. Samples for consolidation test were compacted and then cured for 7, 28 and 56 days; then subjected to one dimensional consolidation testing to observe the influence of curing period and compactive effort on its consolidation characteristics. Index tests showed improved geotechnical properties. The Maximum Dry Density (MDD) for BSL compaction decreased with a rise in RHA content from 1.72 to 1.42 Mg/m^3 while optimum moisture content (OMC) increased from 16.5% to 27.3% with rise in RHA doses from 0% up to 16%. Similar trend was observed for WAS and BSH energies. Pre-consolidation pressure rise with increment in RHA content and also with increase in both compactive efforts and curing period with few exceptions. At 12% RHA content, Pre-consolidation pressure increased from 65 to 66.5 kN/m^2 at 7 days and 56 days respectively. Increase in RHA content caused a decrease in Compression Index and Swelling Index. Compression Index also decreased with increase in both compactive efforts and curing period. There was no observed trend in the Swell Index with curing period. As the compactive efforts increased, the swell index decreased. The RHA reduced the Coefficient of Volume Compressibility (Mv) and the Coefficient of Consolidation (Cc). Curing period and compactive effort have no effect on Mv and Cc. Based on the results obtained, curing period at least 28 days using up to 12% RHA compacted at energy level of BSH improved the properties of the treated soil and can be used for geotechnical engineering applications like embankment or rural roads.

Keywords: Coefficient of consolidation, Compactive effort, Compression index, Curing period, Gross yield stress, Swelling index,

1.0 INTRODUCTION

One of the main uses of an embankment is to store water [1]. Generally, a pile of soil is placed on top of the embankment, which has the potential to collapse, that can be affected by the diffrence in geometry, especially the angle of slope form on an embankment [2]. At the steeper slope, the slope's stability will be reduced that will eventually cause landslide [3]. In order to evaluate whether an embankment will collapse or not, slope stability analysis is done [4].

This research is focused on analyzing Manyar Pond's slope stability and the results are based on its Safety Factor (SF) value and its total displacement value, by using Finite Element Method (FEM), which has an advantage not to use assumptions to identify the failure planes [5]. Manyar Pond has a height of 4.5 meters and graded slopes of 1:2 and 1:5. The calculation of the SF values are done according to the construction stages. On every addition of a soil pile, the embankment has different height and angle of slope. The results will show how the geometry of the soil piles can affect the stability of Manyar Pond, based on the safety factor values and total displacement amplitudes.

This research also explain several stability conditions, if the live loads are placed on different parts of the embankment. Effect when storing large amounts of water will increase effect of the hidrostatic pressure on the bottom of embankment [21]. It is necessary to have slope stability to keep the hydrostatic pressure from damaging the slope stability on the embankment. Therefore, Mohr-Coulomb Failure and Slope Stability analysis are used, which is also combined with Finite Element Method (FEM).

Mohr-Coulomb Failure

Mohr-Coulomb failure happened on a combination of critical conditions of normal stress and shear stress [6]. The Mohr-Coulomb failure criterion is written on the equation below [7] :

$$\tau_f = c + \sigma_f \tan \emptyset \quad (1)$$

with τ_f as shear strength on the failure plain, σ_f as normal stress on the failure plain, c as cohesion, or the pulling force between two or more soil particles, and $\emptyset$ as the internal friction angle.

Slope Stability

Slope stability analysis is needed to assess the safety factor of a artificial embankment, as well as the potential landslide occurance [8]. Stability of the slope is evaluated based on its safety factor values [9]. Safety factor value is a ratio of the force that holds the soil particles (holding force) to the ones triggers soil movements (moving force), which is written on the equation below [10] :

$$F = \tau / \tau_d \quad (2)$$

with τ as shear resistance of the soil, τ_d as shear stress of the soil that is about to collapse, and F as safety factor [10]. Slope can be considered "safe", where landslide rarely happens, if the safety factor are above 1.25 [11].

Finite Element Method

Finite Element Method is one of the slope stability numerical analysis that does not use any assumptions to determine the critical and failure planes on the embankment's slope [12]. Generally, this method divides the surface of the embankment into several district units that is known as elements [13]. The safety factor values resulting from this method is determined using the Shear Strength Reduction (SSR) method [14], where the safety factor value is equal to the reduction factor of c (cohesion) and tan ϕ (internal friction angle) parameters, written on the following equations [13] :

$$RF = \tan \emptyset_{input} / \tan \emptyset_{reduced}$$
$$= C_{input} / C_{reduced} \quad (3)$$
$$SF = RF_{at\ failure} \quad (4)$$

With RF as reduction fator on every calculation steps, tan $\emptyset_{input}$ and c_{input} as soil's input parameters, also tan $\emptyset_{reduced}$ and $c_{reduced}$ as the soil's parameters that have been reduced by the program.

2.0 METHODOLOGY

Data Input

This research uses secondary data that includes Manyar Pond's technical information as well as the soil physical and mechanical parameters. Manyar Pond has a height of 4.5 m and graded slopes of 1:2 and 1:5, with a water level on the elevation of 2.7 m (Figure 1). Manyar Pond has soft clay as its primary soil layer, based on the N-SPT test results. Meanwhile, the soil pile on top of it consists of compacted clay and limestones: limestone boulders on the bottom part of the pile, and compated ones above. Besides that, geotextiles with a specificarion of Unggul-Tex UW 150 and a stiffness of 56.06 kN/m, are located on elevations 2.5 m and 3 m, which are used to support the embankment, as the reinforcement forces. The parameter values of the primary soil layer and the piles are written on Table 1. All of the values written there are the results of soil analysis, where laboratory test results are compared to correlation values from other references ([15], [16], [17], [18], [19], dan [20]), and the most critical values are chosen.

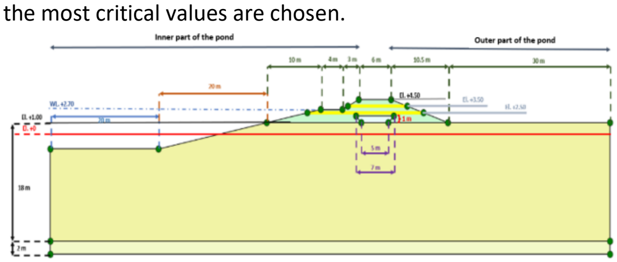


Figure 1 The Geometry of Manyar Pond

Table 1 Soil Parameter Values of Manyar Pond

Parameter	Symbol	Unit	Primary Soil Layer 1	Primary Soil Layer 2	Compacted Clay	Limestone
Depth	-	m	0-18	18-20	-	-
Dominant Lithology	-	-	Clay	Clay	-	-
N-SPT	-	-	1-3	4-5	-	-
Critical N-SPT	-	-	1	4	-	-
Consistency	-	-	Very Soft	Soft	Stiff	-
Unsaturated Unit Weight	γ_{unsat}	kN/m³	10,95	12,75	17,95	16,015
Saturated Unit Weight	γ_{sat}	kN/m³	14,6	16	20	18,53
Unit Weight of Water	γ_{water}	kN/m³	9,8	9,8	9,8	9,8
Cohesion	c	kPa	13,631	10	100	2

Internal Friction Angle	ϕ	°	5	5	5	30
Dilatation Angle	ψ	°	0	0	0	5
Permeability	k	m/day	21 x 10^{-6}	48 x 10^{-5}	9 x 10^{-6}	39 x 10^{-4}
Liquid Limit	LL	%	97,69	68,5	25,9	37
Modulus Young	E	kPa	1.380	2.415	13.800	40.000
Poisson's Ratio	μ	-	0,25	0,25	0,3	0.3
R-Inter	-	-	-	-	-	0,85

Data Processing

Several inputs will be done on Manyar Pond's model that has been made on the program, based on the geometry and measurements of the secondary data. A 10 kN/m^2 live load is inputted on the inner part of the embankment (Figure 2), on the top part of the embankment (Figure 3), and on the outer part of the embankment (Figure 4). Figures 2, 3, and 4 show the different placements of live load (representing human activities and transportation) in order to evaluate several stability conditions.

The calcuation of safety factor value uses the phi-c reduction method, based on the construction stages and the duration required for each steps. The results are in a form of safety factor values and total displacement amplitudes for each construction stages.

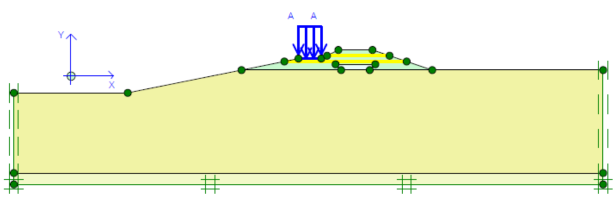


Figure 2 Live Load Placement on the Inner Part of Manyar Pond

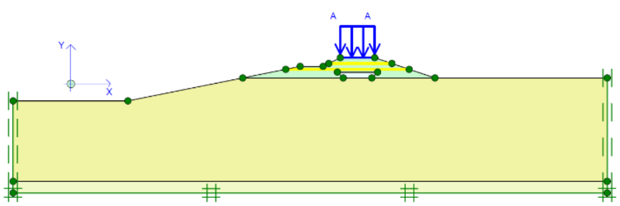


Figure 3 Live Load Placement on the Top Part of Manyar Pond

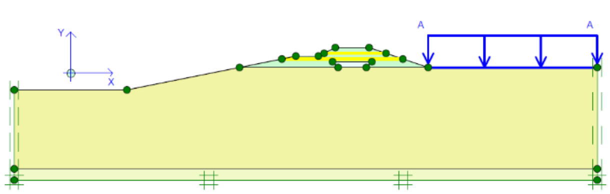


Figure 4 Live Load Placement on the Outer Part of Manyar Pond

3.0 RESULTS AND DISCUSSION

Safety Factor Value

Slope stability analysis was carried out based on safety factor values and total displacement amplitudes that result in each stage of construction. Table 2 shows the safety factor values in each construction duration stage of the Manyar Pond.

Table 2 Safety Factor Values of the Manyar Pond.

Stages	Elevation (m)	Safety Factor Values
Adding of pile soil 1	1 – 2.5	3.3146
Adding of pile soil 2 + Geotextile	2.5 – 3.5	2.7314
Adding of pile soil 3 + Geotextile	3.5 – 4.5	2.4601
Live load input	3 m (on the inner part of the embankment)	2.3819
	4.5 m (on the top part of the embankment)	2.3312
	1 m (on the outer part of the embankment)	2.4356

Based on the results in Table 2, the safety factor values in each construction stage categorized Manyar Pond as "safe" (safety factor values > 1.25 [11]). In each load addition such as pile-soil and live load, the value of the safety factor decreased. The addition of load in the primary soil layer will increase shear stress values which occurred in the soil so that the result value of the safety factor will decrease. At the stage of adding pile-soil 2, the value of the safety factor experienced a significant decrease in value of 0.5832 or 17.59% from the first pile-soil addition stage. It could happen because the second pile-soil embankment has a steeper slope (1:2) than the first pile-soil embankment (1:5) (Figure 5). The steeper slope will increase the thrust force on the soil, resulting a reduced safety factor value by a considerable amount. Meanwhile, at the stage of adding pile-soil 3, the value of the safety factor decreased by 0.2713 or 9.93% because the slope gradient of the third pile-soil embankment was still the same as the second pile-soil embankment. The value of the safety factor occurred at the live load input stage produces different values depending on the location of the live load. The difference in the safety factor value is related to the total displacement that occurs in the soil. This case is going to be explained in the next section on the total soil displacement amplitude analysis.

Total Displacement

The total soil displacement describes how much the soil material moves from its original position. Table 3 shows the amplitudes of total soil displacement in Manyar Pond, which were obtained from the slope stability processing.

Table 3 Total Displacement Amplitudes of Manyar Pond

Stages	Elevation (m)	Total Displacement Amplitudes (m)
Adding of pile soil 1	1 – 2.5	0.104
Adding of pile soil 2 + Geotextile	2.5 – 3.5	0.144
Adding of pile soil 3 + Geotextile	3.5 – 4.5	0.197
Live load input	3 m (on the inner part of the embankment)	0.203
	4.5 m (on the top part of the embankment)	0.228
	1 m (on the outer part of the embankment)	0.189

Based on the results in Table 3, the amplitudes of the total displacement that occurs in the soil will increase with each addition of pile-soil and live load. If a load is applied to the soil surface, compression of the total volume of the soil will occur, which indicates that there is both vertical and horizontal soil displacement.

In addition, there is a total displacement contour (Figure 5) at each load addition stage, with blue color indicating the area with the smallest total soil displacement amplitudes and red color indicating the largest total soil displacement amplitudes area. In Figures 5a, 5b, and 5c, the left side of the embankment slope (the inner part of the embankment) is the area with the largest total soil displacement amplitudes (shown by the red contour). It could happen due to the influence of the thrust force on the slope area that moves the soil mass. It can be identified through the contour that the direction of the total displacement in Manyar Pond (shown by black arrow) pointing to the inner side of the embankment or a failure with a type of LR (Left to Right). Meanwhile, the outer side (the left side of the embankment slope) tends to be flat so that no soil mass movement occurs, indicated by the blue color in the contour.

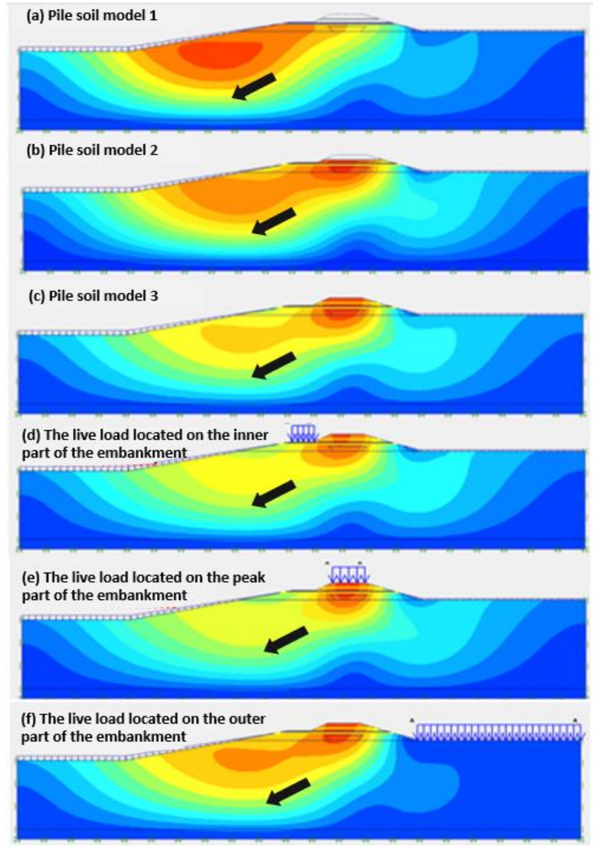


Figure 5 Total Soil Displacement Contour in Each Construction Stage

At the live load input stage, the resulting total displacement has a different amplitude. The live load located on the top part of the embankment has a larger total displacement amplitude (0.228 m) than on the inner part (0.203 m) and the outer part (0.189). It corresponds to the resulting safety factor value at the stage of live load input, which is the live load located on the top part has a smaller safety factor value (2.3312) than on the inner part (2.3819) and the outer part (2.4356) of the embankment.

Figure 5e shows that the live load located on the top part of the embankment has direct contact with the steep slope (1:2), resulting in a large thrust force on the slope face, a considerable size of soil movement occurs that resulting in a larger total displacement amplitude. In contrast to the live load located on the inner part of the embankment (Figure 5d), it is above the embankment slope with a gentle slope (1:5) which shows a smaller thrust force and a little movement of soil mass occurs. The application of live load on the outer part of the embankment (Figure 5f) did not affect the total displacement of the soil, indicated by the smaller displacement compared to the addition of the pile-soil. It could happen because the live load was located on a flat plane and did not have direct contact with the embankment slope. Therefore, the top part of the embankment was a critical part when a load was applied compared to the inner and outer parts, indicated by a large total displacement amount and a smaller safety factor value.

If studied from the type of soil in the Manyar Pond area, the soil type is clay as primary soil and compacted boulder limestones as pile soil. Vertical ground motion. This ground motion has a large displacement amplitude. The large displacement amplitude is influenced by the type of soil that has a fine texture and grain size. In the zone based on the data from the N-SPT test results, it is included in the type of clay soil that has a fine texture and grain size with a displacement amplitude value of 0.1-0.2 m. Clay as the primary soil in the reservoir, has a role as a water retainer in the pond because it has low infiltration which means the absorption of water with a low percentage [7]. While on the pile soil, compacted boulder limestones are used which have a larger soil grain size so that the limestone infiltration value is large and water flows to the part of the soil that holds the pond (in manyar ponds, namely clay soil) [21]. The effect of this soil accumulation can increase the safety factor and slope stability by about 3 % to 7 %, this can be seen from the results of the live load input safety factor and the addition of pile soil with a safety factor value range of 2-3.31 [22]. If further analysis is carried out, a slope stability study is needed that examines the effect of water level in Manyar Pond so that it is known the effect of pore pressure by water on the soil and its relationship to changes in slope stability [23] [1][5].

4.0 CONCLUSION

Based on the calculation of safety factor value using finite element method, Manyar Pond is categorized as "safe". Safety factor value on the last stage of soil pilling is 2.461 with a total displacement of 0.197 m. By adding the soil pillings, making the angle of the slope steeper, makes a greater shear stress that will reduce the embankment's safety factor value. The geometry of Manyar Pond is capable to resist live load on every parts of the embankment, either its on the top, inner, or outer part, with safety factor values all above 1.25. When live load is placed on the top part, the embankment has the lowest safety factor value (2.3312), compared to if it is placed on the inner part (2.3819) and outer part (2.4356), because the slope angle is steeper on the top part of the embankment. If further analysis is carried out, a slope stability study is needed that examines the effect of water level in Manyar Pond so that it is known the effect of pore pressure by water on the soil and its relationship to changes in slope stability

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References

[1] H. A. Utami, G. S. Nalendra, S. Sriyana, and P. Nugroho, 2015. "Perencanaan Embung Somosari di Jepara," Jurnal Karya Teknik Sipil, 4(4): 529–537

[2] Y. Syahwaner, M. Yusa, and S. Satibi, 2019 "Analisis Stabilitas Lereng Dengan Perkuatan Tiang Menggunakan Metode Elemen Hingga (Studi Sasus Jalan Diponegoro Km. 2 Pasir Pengaraian)," *APTEK*, 11(1): 49–58.

[3] R. Manurung, N. S. Surjandari, and N. Djarwati, 2016. "Analisis Stabilitas Lereng Berdasarkan Hujan 3 Hari Berurutan di DAS Tirtomoyo (Studi kasus Desa Damon, Hargorejo, Wonogiri)," *Matriks Tek. Sipil*, 4(1): 97–105

[4] Setyanto, A. Zakaria, and G. W. Permana, 2016. "Analisis Stabilitas Lereng dan Penanganan Longsoran Menggunakan Metode Elemen Hingga Plaxis V.8.2," *Jurnal Rekayasa* 20(2): 119–138,

[5] M. M. Sazzad, F. I. Rahman, and M. A. A. Mamun, 2016. "Effects of Water-Level Variation on the Stability of Slope By Lem and Fem," February: 978–984

[6] Darwis, 2018. *Dasar-Dasar Mekanika Tanah*, no. January. Pena Indis,

[7] I. N. Hamdhan and D. S. Pratiwi, 2017. "Analisis Stabilitas Lereng dalam Penanganan Longsoran di Jalan Tol Cipularang Km. 91+200 dan Km. 92+600 Menggunakan Metode Elemen Hingga (FEM)," *Jurnal Rekayasa Hijau ISSN 2550-1070*, I(2): 100–111

[8] Standar Nasional Indonesia, 2017. *SNI 8460: 2017; Perancangan Geoteknik*. Jakarta: Badan Standardisasi Nasional,

[9] B. M. Das, 1995. *Rekayasa Geoteknis*

[10] T. G. S. Putra, N. Aribudiman, and G. R. Juliawan, 2016. "Analisis Stabilitas Lereng Pada Bendungan Titab," *Jurnal Ilmiah Teknik Sipil* 20(1): 1689–1699,

[11] Sepriadi and A. M. Prastowo, 2019. "Analisis Kestabilan Lereng Dengan Metode Kesetimbangan Batas Pada Lereng High Wall PIT 1 Utara Tambang Banko Barat Menggunakan Software Geostudio Slope/W 2018 di PT Bukit Asam, Tbk. Tanjung Enim, Sumatera Selatan," *Tek. Patra Akad.*, 10(01): 58–76

[12] H. M. Shiferaw, 2021, "Study on The Influence of Slope Height and Angle on The Factor of Safety and Shape of Failure of Slopes Based on Strength Reduction Method of Analysis," Beni-Suef University Journal of Basic and Applied Sciences 10(31): 1-11. doi: 10.1186/s43088-021-00115-w.

[13] A. EE and O. CC, 2017, "Finite Element Method of Stability Analysis and Stabilization of Gully Erosion Slopes - A Study of the Otampa Gu," *Journal of Civil and Environmental Engineering* 07(01): 1–8, doi: 10.4172/2165-784x.1000267.

[14] Y. Ishii, K. Ota, S. Kuraoka, and R. Tsunaki, 2012, "Evaluation of slope stability by finite element method using observed displacement of landslide," *Landslides*, 9(3): 335–348, doi: 10.1007/s10346-011-0303-7.

[15] H. Wahyudi, 1999. *Daya Dukung Pondasi Dangkal*. Institut Teknologi Sepuluh Nopember, Surabaya

[16] Reza Satria Warman 2019. "Kumpulan Korelasi Parameter Geoteknik dan Fonfasi,"Kementrian Pekerjaan Umum dan Perumahan Rakyat,Direktorat Jenderal Bina Marga

[17] H. Wahyudi, 2005. "Foundation Problem - Herman Wahyudi.pdf." Institut Teknologi Sepuluh Nopember, Surabaya

[18] M. Barik, 2010, "Landslide Susceptibility Mapping To Inform Landuse Management Decisions in an Altered Climate," May: 55, doi: 10.13140/RG.2.1.2668.2968.

[19] M. R. Lindeburg, 2003.*Civil Engineering Reference Manual for the PE Exam*. Professional Pubns Inc

[20] N. Sabina and C. A. Makarim, 2020, "Proses Analisa Dinding Galian Basement 7 Lantai Dengan Metode Elemen Hingga," *Jurnal Mitra Teknik Sipil* 3(1): 49. doi: 10.24912/jmts.v3i1.6980.

[21] R. Permatasari, 2017, "Pengaruh Perubahan Penggunaan Lahan terhadap Rezim Hidrologi DAS (Studi Kasus : DAS Komering)," *J. Tek. Sipil ITB*, 24(1): 91–98, doi: 10.5614/jts.2017.24.1.11.

[22] A. Fauzi, S. Sukobar, D. I. Wahyudi, and R. A. T. Moeljono, 2019, "Analisa Stabilitas Lereng dan Alternatif Penanganannya Studi Kasus Proyek Pekerjaan Kanal Utama Row 80 Kawasan Industri JIIPE-Gresik," *J. Apl. Tek. Sipil*, 17(2): 59, doi: 10.12962/j2579-891x.v17i2.5447.

[23] J. S. Frans and M. H. Nurfalaq, 2019, "Geotechnical Study of The Impact of Groundwater Level For Slope Stability in Coal Mine," *Indonesia Mining Proffesionals Journal*, 1(1): 12–21, doi: 10.36986/impj.v1i1.7.