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Effects of Gravel Percentage to Compaction Density and Stability of Embankment

Eka Sukmawati, Dian Purnamawati Solin*, and Himatul Farichah

Department of Civil Engineering, Faculty of Engineering, UPN "Veteran" Jawa Timur, 60294, Indonesia

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ABSTRACT

Embankments are frequently used in the construction of road, railway, airport, dams and other types infrastructure. Soil compaction is a crucial part of the construction process of embankment. Thus, soil compaction needs to be conducted and investigated in such a way so embankment will not experience large settlement that could lead to collapse. Generally, soil compaction density testing is performed using the sand cone method according to ASTM D-1556. The material used in this test is not carefully considered, which may lead to inaccurate results. In this study, the sand cone correction test according to ASTM D-4718 which consider the percentage of gravel is established to identify the compaction density of embankment and the effect to its stability. 16 secondary data of compaction density have been collected from the construction of embankment. According to the data, the compaction density of the embankment has met the specifications. The relationship between the gravel percentage and the compaction density is obtained. With a determination coefficient (R^2) value of 0.805, it can be understood that these two variables have a highly significant correlation. Furthermore, to understand the relationship between the compaction density and the stability of the embankment, a slope stability analysis was conducted on the embankment using the Fellenius method. The result shows that when the compaction density of the embankment meet the specifications, embankment is stable with the safety factor (SF) of 1.511. Furthermore, both variables have a very strong relationship. The safety factor of the embankment is increased as the compaction density increases.

1. Introduction

On uneven ground contours and poor soil conditions, embankment work is required before building structures. In various construction projects, backfilling is carried out with different heights according to soil conditions and the type of construction to be built. In this case, it is needs to analyze the data correcting so that the structure above it can stand without any settlement that can cause collapse.

Compaction density involves the technical of the sand cone method using Ottawa sand as the soil density standard. Ottawa sand has dry, clean, and hard characteristics, and has no adhesive substance so that it can flow freely. This sand cone test aims to measure soil density at field locations, both in soil layers and pavement layers that have undergone the compaction process [1].

The material used in the sand cone compaction test has not been carefully considered, leading to possible errors in the results of the sand cone test. This technique only applies to the topsoil with a Thickness of about 10 to 15 cm. In addition, the described test method is applicable only to soil and rock particles with a diameter not exceeding 5 cm [2]. This test method can be used on soils that do not contain much rock or coarse material, as long as there is sufficient quantity and greater than 1 ½ inch diameter. If the compaction test is performed on compaction density and obtains results in accordance with ASTM D1556 or SNI 03-2828-(1992), it should be viewed with skepticism. The possibility of measurement errors or hole volume problems must be taken into account [3].

To prevent errors in the sand cone testing as specified by ASTM D1556 and SNI 03-2828-(1992) standards and to meet the required specifications, the density test is

*Corresponding author.
E-mail: diansolin.ts@upnjatim.ac.id

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conducted using the sand cone correction method according to ASTM D-4718. In practice, this method is performed on soil and soil-rock mixtures where the portion considered too large is the fraction of material retained on the 4.75 mm (No.4) sieve. Based on this test, the method can be applied to both soil and soil-rock mixtures where up to 40% of the material is retained on the sieve with a 4.75 mm [No. 4] opening. This method is also considered valid if the larger-sized fraction is retained on another sieve, even though the correction percentage for larger-sized particles may be lower. However, this method is deemed acceptable for materials with a larger-sized particle content up to 30% if the larger-sized fraction is retained on the sieve with a 19 mm [3/4 inch] opening [4].

This study present compaction density carried out by the sand cone correction method D-4718. The effect of the percentage of gravel and the compaction density was investigated in this study. Furthermore, the stability of the embankment is also calculated using Fellenius method to investigate the relationship of the safety factor (SF) and the compaction density of the embankment.

2. Materials and Method

The research process begins with the collection of necessary data, especially the collection of secondary data to support the research process, such as D-4718 correction sand cone data, boring log, embankment material specifications and others. from the data of the sand cone correction method D-4718, the percent value of the percentage of gravel and the compaction density result were obtained to determine the relationship between these two values by simple overlay regression. while determining the safety factor (SF) happen in the embankment is done by correcting the parameters of the embankment.

2.1 Sand cone

The sand cone correction method D-4718 is conducted to directly obtain the compaction density of embankment values. The sand cone correction method D-4718 is performed similarly to the sand cone test ASTM D-1556, but in the D-4718 sand cone test, a sieve analysis is carried out to determine the percentage of wet weight retained and wet weight passing through the materials used in the field. Additionally, the moisture content of the retained wet weight is tested using an oven [3] [4].

2.2 Simple Linear Regression

Simple linear regression method is a technique used to identify the relationship between an independent variable that has a linear connection with a dependent variable [5] [6]. In this study, the independent variable referred to is the percentage of gravel while the dependent variable is the percentage compaction density of embankment. The data from the field testing is presented in accordance in Table 1.

$$r = \frac{\sum xi.yi}{\sqrt{\sum xi^2 . \sum yi^2}} \quad (1)$$

with:
xi = xi – xrt
yi = yi – yrt
xi = the value of x in data 1
yi = the value of y in data 1
xrt = mean value of x
yrt = mean value of y

The correlation coefficient value obtained from the above calculation determines the strength of the relationship between variables, as described in the following Table 2. Once the correlation coefficient is obtained, guidelines from Table 3 are used to interpret the correlation coefficient. The coefficient of determination, denoted as R^2, is a determining coefficient, indicating that the strength of the relationship between the variables (y) is determined by the variable (*x*) to the extent of R^2 [7].

Table 1. Example table of percentage of gravel and compaction density

No.	Percentage of gravel (x_i)	Compaction density (y_i)
1.	6.88	100.92
2.	13.63	101.63
3.	17.78	102.30
4.	18.07	103.50
5.	22.67	104.10
6.	28.13	103.99
7.	19.23	102.98
8.	22.32	103.53
9.	13.73	101.20
10.	27.39	104.44
11.	30.80	105.05
12.	23.40	103.72
13.	40.20	106.73
14.	27.52	104.46
15.	16.64	103.10
16.	35.91	103.70

Table 2. Coefficient of correlation [6]

Correlation coefficient	Information
1	The perfect positive relationship
0.6 – 1	Positive direct relationship is good
0 – 0.6	Weak positive direct relationship
0	There is no linear relationship
-0.6 – 0	Weak negative direct relationship
-1 - -0.6	Negative direct relationship is good
-1	Perfect negative direct relationship

Table 3. Interpretation of the Correlation Coefficient [7]

No.	Coefficient Intervals	Relationship Level
1	$0 \le r \le 0.199$	very low
2	$0.2 \le r \le 0.399$	low
3	$0.4 \le r \le 0.599$	currently
4	$0.6 \le r \le 0.799$	strong
5	$0.8 \le r \le 1.000$	very strong

In addition to determining the relationship between variables, to ensure that there is no settlement leading to collapse, an analysis of embankment stability is conducted. This analysis using to determine the safety factor (SF) value, which is based on the results of the sand cone correction method D-4718 and the correlation of soil parameters required for the analysis. In calculating the embankment stability analysis, this study uses the Fellenius approach (Ordinary Method of Slice).

2.3 Embankment stability using the Fellenius method

The Fellenius method was introduced for the first time by Fellenius (2014). This method is based on the principle that forces have slopes parallel to the failure surface and calculations are conducted considering the equilibrium of moments. Fellenius presented his approach assuming that failure occurs through the rotation of a soil block on a circular slip surface with point O as the center of rotation. This method also considers that the normal force (Nr) acts at the midpoint of the slice as Figure 1 [8]. This stability calculation also assumes that the slope failure is in the form of a circular arc, and the analysis to determine the most critical safety factor (SF) is conducted experimentally for various circles with center points and radius [9].

By applying the fundamental principles and assumptions, the analysis of the safety factor (SF) can be elaborated. The calculation of soil unit weight is performed using the following Equation 2.

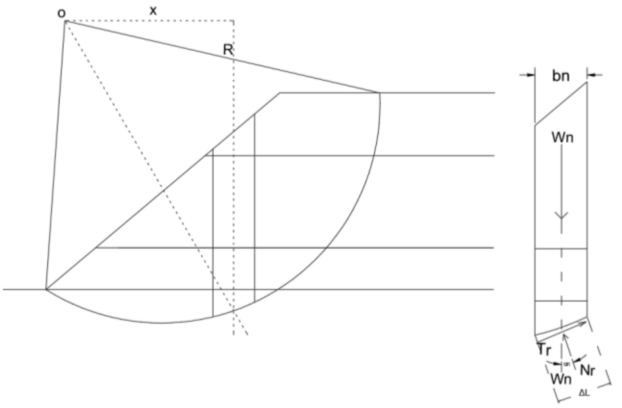

Figure 1. Slope with circular arc slip surface

$$Wn = \gamma_{sat} \times A \qquad (2)$$

With W_n is the soil weight (kN/m), γ_{sat} is the weight of soil in saturated condition (kN/m^3), and A is the segment of area (m^2).

On the other hand, for slices that have loads above them, the weight of the slice can be calculated using the following Equation 3.

$$Wn = (\gamma \times A) + (q \times L) \qquad (3)$$

where q represents the magnitude of the load and L is the width of the slice affected by the load (meters). Next, the calculation of the inclined arc line is performed with bn being the width of the slice. The following in Equation 4.

$$\Delta l = bn/\cos \alpha \qquad (4)$$

To ensure slope stability, the forces required to induce sliding must be lower than the resisting forces, resulting in an increase the safety factor with the following Equation 5.

$$Nr = W\ cos\alpha \qquad (5)$$

After that, we determine the resisting forces (Tr) and driving forces (Td) on the slice, according to the Equation 6 and Equation 7.

$$\text{Tr} = \sum_{n=1}^{n=p} (C.\Delta l + Wn \cos\alpha\ tan\varphi) \qquad (6)$$

$$\text{Td} = \sum_{n=1}^{n=p} Wn\ sin\alpha \qquad (7)$$

The value of the safety factor (SF) is the ratio between the total resisting forces of sliding and the driving forces/causes of sliding for all slices, expressed with the following Equation 8.

$$\text{SF} = \frac{\text{Tr}}{\text{Td}} = \frac{\sum_{n=1}^{n=p}(C.\Delta l + Wn \cos\alpha\ tan\varphi)}{\sum_{n=1}^{n=p} Wn \sin\alpha} \qquad (8)$$

For rock slopes, the required safety factor (SF) is shown in Table 4, considering the permanent or temporary conditions of the planned rock slope. In rock slopes, the influence of water needs to be considered. If the groundwater level is high and efforts are needed to lower the groundwater level within the rock mass to enhance safety factor, then groundwater level reduction can be achieved using horizontal drilling as drainage to channel water out of the rock mass. Table 4 provides recommended safety factor values for rock slopes [10]. The required slope safety factor (SF) for soil slope stability analysis is shown in Table 5, based on considerations of cost and the consequences of slope failure in relation to the uncertainty level of analysis conditions.

3. Result and Discussion

3.1 Mathematical Model of Regression Line Equations

From the sand cone correction method D-4718, which was conducted, values of the percentage of gravel and the percentage of compaction density of embankment were obtained. These values were subsequently used to determine the relationship between the two. The mathematical model calculations for both can be seen in Table 6.

Thus, the calculation of the correlation coefficient is done using the Equation 9.

$$r = \frac{\sum xiyi}{\sqrt{(\sum xi^2 . \sum (yi^2))}} \quad (9)$$

$$r = \frac{172{,}00}{\sqrt{1129{,}04 \times 32{,}57}}$$

$r = 0.90$

$R^2 = 0.805$

Because the correlation coefficient value is r = 0.90, it indicates a relationship between the percentage of gravel and the compaction density resulting from the sand cone correction method D-4718. This relationship is a strong direct positive correlation, meaning the relationship between the independent variable (x) and the dependent variable (y) is very strong, with a percentage of 90%. Thus, density is highly influenced by percentage of gravel, as described in Table 2. The correlation coefficient value and the strength of the relationship between the variables [6]. On the other hand, the coefficient of determination can be determined by squaring the correlation coefficient. From the data above, the coefficient of determination is R^2 = 0.805. This result means that 80% of the variance in the independent variable (x) can explain the variance in the dependent variable (y), while the remaining 20% is explained by other variables. If presented in graphical form, it would look like the illustration below Figure 2.

With an R^2 value of 0.805, it indicates that the relationship between percentage of gravel and compaction density of embankment is very strong. In addition to the data, in the sand cone correction according to ASTM D-4718, some data that did not meet the specifications were taken to determine the relationship between them. This is shown in the Table 7 and Figure 3.

Table 4. Recommended Safety Factor Values for Rock Slopes

Condition of Rock Slopes	Recommended safety factor values
Permanent condition	1.5
Temporary condition	1.3

Table 5. Recommended safety factor values for soil slopes

Cost of Consequences of Slope Sliding	Measurement Uncertainty of Shear Strength Parameters	
	Small	Big
Repair costs compared to construction are the same. No danger to human life or other property	1.25	1.5
Repair costs are greater than construction costs, and dangerous to human life or other properties	1.5	≥2

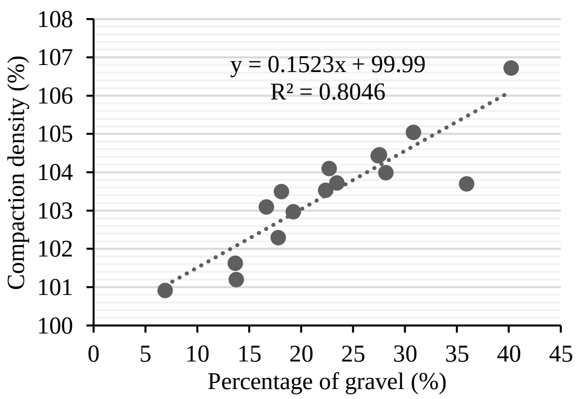

Figure 2. Linear regression analysis equation

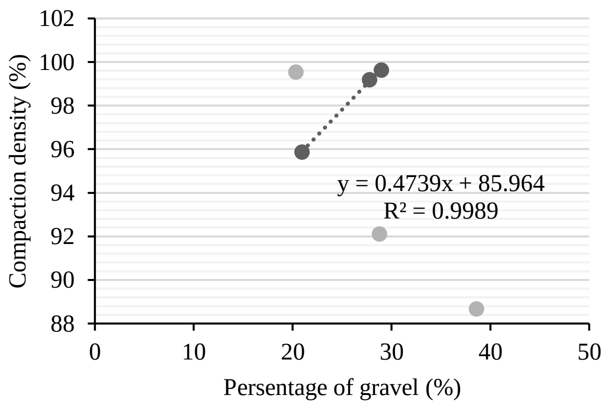

Figure 3. Linear regression analysis equation

Table 6. Results of compaction density and percentage of gravel of sand cone correction method d-4718 according to specifications

No	Percentage of gravel (%)	Compaction density (%)	xi	Yi	xi^2	yi^2	xi.yi
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	6.88	100.92	-15.89	-2.54	252.45	6.44	40.33
2	13.63	101.63	-9.14	-1.83	83.52	3.34	16.71
3	17.78	102.30	-4.99	-1.16	24.89	1.34	5.78
4	18.07	103.50	-4.70	0.04	22.08	0.00	-0.20
5	22.67	104.10	-0.10	0.64	0.01	0.41	-0.06
6	28.13	103.99	5.36	0.53	28.74	0.28	2.85
7	19.23	102.98	-3.54	-0.48	12.52	0.23	1.71
8	22.32	103.53	-0.45	0.07	0.20	0.00	-0.03
9	13.73	101.20	-9.04	-2.26	81.70	5.10	20.41
10	27.39	104.44	4.62	0.98	21.36	0.95	4.52
11	30.80	105.05	8.03	1.59	64.50	2.52	12.74
12	23.40	103.72	0.63	0.26	0.40	0.07	0.17
13	40.20	106.73	17.43	3.27	303.85	10.68	56.96
14	27.52	104.46	4.75	1.00	22.57	1,00	4.75
15	16.64	103.10	-6.13	-0.36	37.56	0.13	2.20
16	35.91	103.70	13.14	0.24	172.69	0.06	3.18
Σ	364.30	1655.33	4.2E-14	-5.6E-14	1129.04	32.57	172.00
Average	22.77	103.46	2.6E-15	-3.5E-15	70.57	2.04	10.75

Table 7. Results of compaction density and percentage of gravel of sand cone correction method d-4718 under the specifications

No	Percentage of gravel (%)	Compaction density (%)	xi	yi	xi^2	yi^2	xi.yi
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	28.780	92.110	1.222	-3.727	1.492	13.888	-4.553
2	20.950	95.880	-6.608	0.043	43.670	0.002	-0.286
3	38.570	88.670	11.012	-7.167	121.257	51.361	-78.917
4	28.970	99.630	1.412	3.793	1.993	14.389	5.355
5	27.760	99.190	0.202	3.353	0.041	11.245	0.676
6	20.320	99.540	-7.238	3.703	52.393	13.715	-26.806

From Figure 3, the result of R^2 is 0.9989 indicating a very strong relationship between percentage of gravel and compaction density of embankment, in other words this value is valid and can be used as a reference to show the existence of a relationship between the two variables as in Table 3.

So, in addition from percentage of gravel, the factors influencing compaction density of embankment that is moisture content, sand correction weight in the funnel, weight percentage passing the ¾ sieve, and compaction effort of embankment. An important to consider in earthworks is the compaction density of embankment or dry unit weight. Even if the CBR value meets the standards, if the compaction density of embankment is not optimal, the possibility of deformation due to consolidation still exists, and the load distribution to the embankments layers below may be disrupted [2].

3.2 Analysis of Embankment Stability

Analysis of Soil and Embankment Parameters. In calculating embankment stability, the properties of the soil that need to be known are soil unit weight (γ), internal friction angle (φ), and cohesion (c). Therefore, before conducting embankment stability analysis, it is necessary to perform analysis of SPT test data and embankment data to obtain the required parameters. The results of the embankment data analysis and correlation calculation from the analysis of SPT test data and can be seen in Table 8 and Table 9.

Table 8. Correlation of N-SPT with soil parameters

Depth m	Type of soil	$N1_{(60)}$ Blow/ft	γ_{sat} kN/m³	γ' kN/m³	γ kN/m³	qu kPa	Cu kPa	c kN/m²	v	k m/day	φ °
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	ML	5	18.22	8.22	17.48	59.79	25.00	11	0.2	0.000864	27
2	ML	7	18.28	8.28	17.70	86.58	34.63	14	0.3	0.000864	27
3	ML	12	20.11	10.11	17.10	148.72	59.49	14	0.3	0.000864	27
4	BA	22	20.18	10.18	18.80	272.28	117.82	20	0.35	0.000864	27
5	MH	19	19.86	9.86	18.04	232.99	93.20	20	0.3	0.000864	27
6	MH	13	21.79	11.79	18.00	165.35	66.14	20	0.3	0.000864	27
7	MH	7	19.00	9.00	16.47	82.60	33.04	20	0.3	0.000864	27
8	CH	9	20.11	10.11	17.10	107.09	42.84	11	0.2	0.000864	27
9	CH	11	21.51	11.51	18.00	136.97	54.79	14	0.3	0.000864	27
10	ML	12	19.13	9.13	16.31	149.09	59.64	14	0.3	0.000864	27
11	ML	19	21.31	11.31	21.48	242.88	97.15	14	0.3	0.000864	27
12	ML	23	22.00	12.00	24.30	284.26	127.41	14	0.3	0.000864	27
13	ML	18	21.25	11.25	21.33	220.06	88.02	14	0.3	0.000864	27
14	ML	15	20.58	10.58	19.76	184.94	73.98	14	0.3	0.000864	27
15	ML	13	20.02	10.02	18.42	156.70	62.68	14	0.3	0.000864	27

Table 9. Correlation of embankment data with soil parameters

No	Layer	Thickness m	γ_d kN/m³	γ_{sat} kN/m³	γ_{unsat} kN/m³	Dr %	φ °	c kN/m³	E kPa	kx/ky m/day	v
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1	Coarse grained	1.5	18.86	21.58	19.10	100	45	18.6	200000	0.864	0.2
2	Rockfill	2.2	19.00	21.66	19.43	95	41.43	18.9	200000	0.864	0.2
3	LTP	1	19.00	21.66	19.43	95	41.43	18.9	200000	0.864	0.2

Load Analysis. In the load analysis, calculations are performed for the runway pavement load and the airplane load of the planned Boeing 777-300ER airplane with a Maximum Takeoff Weight (MTOW) value of 351.535 tons and a Maximum Landing Weight (MLW) value of 251.290 tons [11] [12]. The results of the load analysis can be seen in Table 10.

Embankment Stability Analysis using the Fellenius Method. According to the SKBI 2.3.06 guidelines from 1987, this technique can be applied to slopes with isotropic and non-isotropic characteristics, as well as layered structures can be seen in Figure 4. This approach relies on the movement of soil mass that can be divided into several vertical elements. These elements are considered as straight lines [13].

In this method, the sliding is assumed to be in the form of a circular arc, and the analysis to determine the most critical safety factor is done iteratively for various circles with center points and radian. The division of cross-sections in the embankment can be seen in Figure 5.

From Figure 5, a slope with a cross-sectional system for the self-weight of the soil mass (Wn) can be observed. In the bottom part of the cross-section, the weight force (Wn) is decomposed into the normal reaction force (Nr), which acts perpendicular to the cross-sectional base, and the tangential force (Tr), which acts parallel to the cross-section. Embankment stability calculation using equations (3), (4), (5), (6), (7), and (8). From the stability calculation of the embankment using the Fellenius method in Table 11 and Tabel 12, a safety factor (SF) of 1.511 and 1.509 was obtained, indicating that the stability of the embankment meets the requirements as show in Table 4 and Table 5, in other words the embankment is said to have strength more and the condition is stable. Through trial and error in determining the zero (0) point, the most critical safety factor values are obtained as shown in Table 11 and Table 12. The safety factor values increase with the difference in shear strength between the embankment and the original soil layer [14].

Table 10. Load Analysis

No	Thickness m	specific gravity kN/m3	q = Thickness × specific gravity kN/m²	t/m²
1	2	3	4	5
AC-Base	0.085	10.4	0.884	0.0884
AC-BC	0.09	24.2	2.178	0.2178
AC-BC	0.075	24.2	1.815	0.1815
AC-WC	0.06	23.1	1.386	0.1386
Σ			6.263	0.6263
q airplane			5.551	0.5551

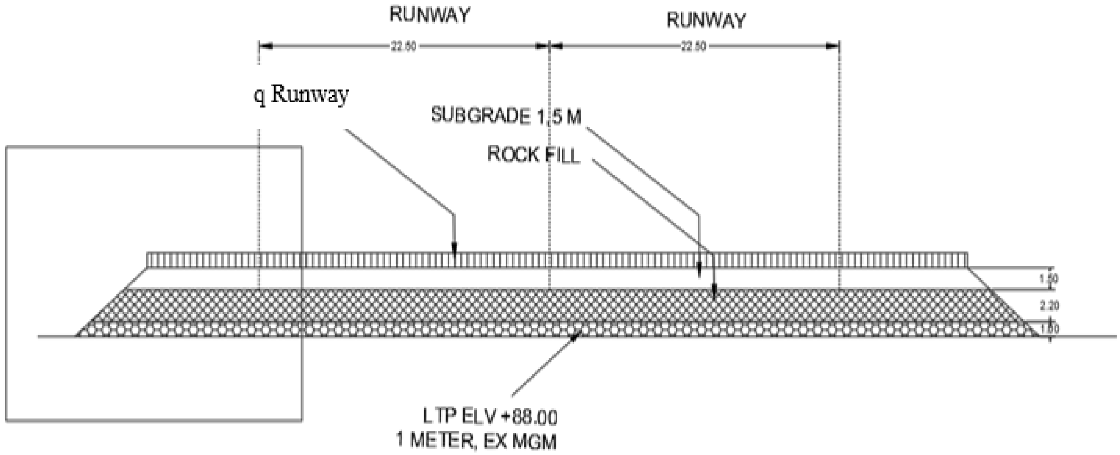

Figure 4. Embankment structure

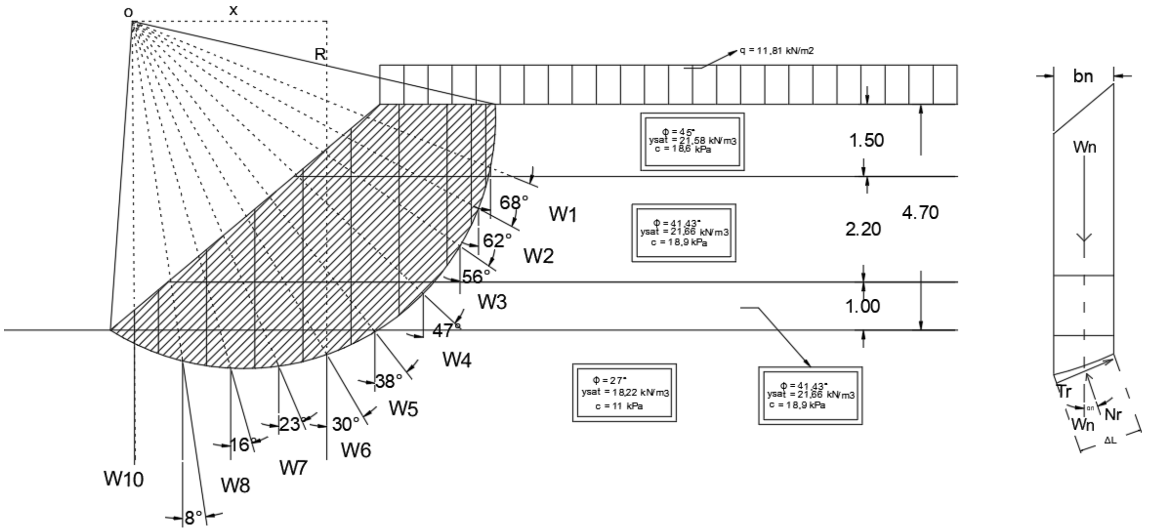

Figure 5. Embankment analysis using the Fellenius Method

Table 11. Calculation of embankment stability analysis using the Fellenius method according to Specification

No	Weight (Wn) kN/m	**α (°)** (deg)	sinα	cosα	**Δl** m	Td=wn sinα kN/m	Nr= Wn cosα kN/m	**Δl.c** kN/m	**φ** (deg)	**tanφ**	**Tr** kN/m
1	2	3	4	5	6	7	8	9	10	11	12
1	5743	68	0.927	0.375	0.53	5.325	2.151	9.930	45.000	1.000	12.082
2	17.284	62	0.883	0.469	0.64	15.261	8.114	12.056	41.430	0.883	19.217
3	54.037	56	0.829	0.559	0.95	44.799	30.217	17.882	41.430	0.883	44.550
4	93.426	47	0.731	0.682	1.47	68.327	63.716	27.664	41.430	0.883	83.897
5	106.247	38	0.616	0.788	1.27	65.412	83.724	23.942	41.430	0.883	97.832
6	90.482	30	0.500	0.866	1.15	45.241	78.359	12.702	27.000	0.510	52.628
7	75.392	23	0.391	0.921	1.09	29.458	69.399	11.950	27.000	0.510	47.310
8	59.422	16	0.276	0.961	1.04	16.379	57.120	11.443	27.000	0.510	40.548
9	38.829	8	0.139	0.990	1.01	5.404	38.451	11.108	27.000	0.510	30.700
10	13.560	0	0.000	1.000	1.00	0.000	13.560	11.000	27.000	0.510	17.909
∑						295.606					446.673
SF											1.511

Table 12. Calculation of embankment stability analysis using the Fellenius Method under the specification

No	Weight (Wn) kN/m	α (°) (deg)	sinα	cosα	Δl m	Td=wn sinα kN/m	Nr= Wn cosα kN/m	Δl.c kN/m	φ (deg)	tanφ	Tr kN/m
1	2	3	4	5	6	7	8	9	10	11	12
1	5.743	68	0.927	0.375	0.53	5.325	2.151	9.930	36.430	0.738	11..518
2	17.284	62	0.883	0.469	0.64	15.261	8.114	12.056	41.430	0.883	19.217
3	54.037	56	0.829	0.559	0.95	44.799	30.217	17.882	41.430	0.883	44.550
4	93.426	47	0.731	0.682	1.47	68.327	63.716	27.664	41.430	0.883	83.897
5	106.247	38	0.616	0.788	1.27	65.412	83.724	23.942	41.430	0.883	97.832
6	90.482	30	0.500	0.866	1.15	45.241	78.359	12.702	27.000	0.510	52.628
7	75.392	23	0.391	0.921	1.09	29.458	69.399	11.950	27.000	0.510	47.310
8	59.422	16	0.276	0.961	1.04	16.379	57.120	11.443	27.000	0.510	40.548
9	38.829	8	0.139	0.990	1.01	5.404	38.451	11.108	27.000	0.510	30.700
10	13.560	0	0.000	1.000	1.00	0.000	13.560	11.000	27.000	0.510	17.909
∑						295.606					446.11
SF											1.509

4. Conclusions

The percentage of gravel and compaction density has been evaluated in this study. Furthermore, the relationship between embankment density and the safety factor has been obtained. The percentage of gravel weight significantly influences soil density. This can be observed from a coefficient of determination (R^2) = 0.805 according to specification (100%), while R2 = 0.9989 obtained from the equation between the percentage of material and the compaction density under the specification, where both show a very strong relationship.

Compaction density of embankments has a significant impact on their stability. This can be seen from soil parameters that influence soil density, such as soil shear strength (φ), cohesion value (c), and so on. The larger the value of these soil parameters, the greater the soil density and embankment stability. Furthermore, this can be observed from the stability modeling results of the embankment using the Fellenius Method, which resulted a safety factor of 1.511. where the safety factor (SF) is 1.509, it can be seen that the embankment is still safe, but it is better if the compaction density does not accordance the specification, the compaction density must be rested so that the compaction density accordance the specifications.

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