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Statistical Analysis and Correlation Between Soil Density (Sand Cone) and Soil Bearing Capacity (Field CBR) in Reclamation Landfill (Case Study: Patimban Port Package 6)

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Abstract

Quality control in the Package 6 Patimban Port reclamation project greatly determines the stability of port operations. This study aims to analyze the correlation between the average soil density (Sand Cone) of layers 1–7 to the surface bearing capacity (Field CBR) of the subgrade and formulate a prediction model. Using a quantitative approach, this study analyzed 26 samples using simple linear regression without a constant (regression through the origin). The results of the analysis showed a very strong and positive correlation relationship with the value of $R = 0.976$. The resulting prediction model is $Y = 0.141X$ with a coefficient of determination (R^2) of 0.953. This proves that 95.3% of the variation in Field CBR values is significantly influenced by the average density of all layers of the landfill. These findings confirm that every 1% increase in average density increases the Field CBR by 0.141%.

Keywords: *Field CBR, Linear Regression, Reclamation, Sand Cone, Subgrade*

Abstrak

Pengendalian kualitas timbunan pada proyek reklamasi Pelabuhan Patimban Paket 6 sangat menentukan stabilitas operasional pelabuhan. Studi ini bertujuan untuk menganalisis korelasi antara rata-rata nilai kepadatan tanah (Sand Cone) lapisan 1–7 terhadap daya dukung (Field CBR) lapisan 7 subgrade serta merumuskan model prediksinya. Dengan pendekatan kuantitatif, penelitian ini menganalisis 26 sampel menggunakan regresi linear sederhana tanpa konstanta (regression through the origin). Hasil analisis menunjukkan hubungan korelasi yang sangat kuat dan positif dengan nilai $R = 0{,}976$. Model prediksi yang dihasilkan adalah $Y = 0{,}141X$ dengan koefisien determinasi (R^2) sebesar 0,953. Hal ini membuktikan bahwa 95,3% variasi nilai Field CBR dipengaruhi secara signifikan oleh rata-rata kepadatan seluruh lapisan timbunan di bawahnya. Temuan ini menegaskan bahwa setiap kenaikan 1% kepadatan rata-rata meningkatkan Field CBR sebesar 0,141%.

Keywords: *Field CBR, Regresi Linear, Relamasi, Sand Cone, Subgrade*

INTRODUCTION

Maritime infrastructure projects, such as the Patimban National Port Project in Subang, West Java, play a crucial role in spurring economic growth and optimizing the national logistics system. Since all important structures, such as docks and terminals, are built on reclaimed land, the quality of material stockpiling work must meet very strict geotechnical standards. Non-compliance with stockpile quality standards can pose significant technical risks such as structural failures that interfere with the port's operational functions. In quality control in the field, the main indicators applied are soil density through the Sand

Cone test and soil bearing capacity through the Field CBR test.

Previous literature has examined in depth the relationship between the two parameters. [1] identified a very strong correlation (0.998) between the CBR and Sand Cone values in the subbase layer. Instead, [2] stated that there was no significant relationship between the two values in the case study of the Simpang Tambue-Lhok Dagang road. Meanwhile, [3] highlight the influence of material properties on compaction quality, although they place more emphasis on CBR testing in the laboratory. These varied findings indicate the presence of specific factors related to the location, type of material, and testing procedures applied.

The scientific novelty of this research is finding empirical evidence of the correlation between the average value of 7-layer soil density and the bearing capacity of the surface soil (layer 7) of the subgrade soil. In contrast to previous studies, which were generally conducted separately or relied on laboratory data, this study utilizes Field CBR data that accurately reflects field conditions and takes into account the Stress Bulb effect, where the bearing capacity of the surface depends on the stiffness of the layers underneath.

Based on the problems described above, this study examines three main aspects, namely: (1) the correlation relationship between the average soil density value in layers 1 to 7 obtained through the Sand Cone test and the Field CBR value in layer 7; and (2) the effect of the average density value of the seven layers on the carrying capacity of the soil. Therefore, the purpose of this study is to identify the relationship between soil density and carrying capacity parameters, developing a simple linear regression model without a constant (regression through the origin) as a predictive approach to field CBR values.

METHODOLOGY

This study applied a quantitative approach with descriptive correlation and linear regression to analyze the correlation between the average density value (Sand Cone) of layers 1 to 7 against the carrying capacity (Field CBR) in layer 7 of the subgrade heap and formulated a simple linear regression equation model without a constant (regression through the origin) to predict the Field CBR based on density data from the 7 layers of the heap.

This case study was conducted on the Patimban Port Reclamation Project Package 6, Subang, West Java, Indonesia. Of all reclamation areas in the Patimban Port Project, Package 6 specific areas were observed, namely areas that were not shaded in Figure 1.

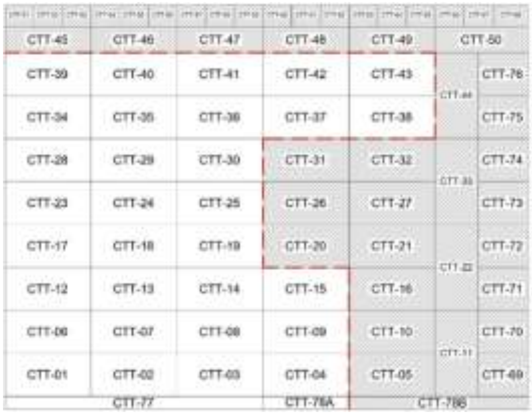

Figure 1. Map of the Observed Area

The research workflow from the introduction to the conclusion is systematically summarized in Figure 2.

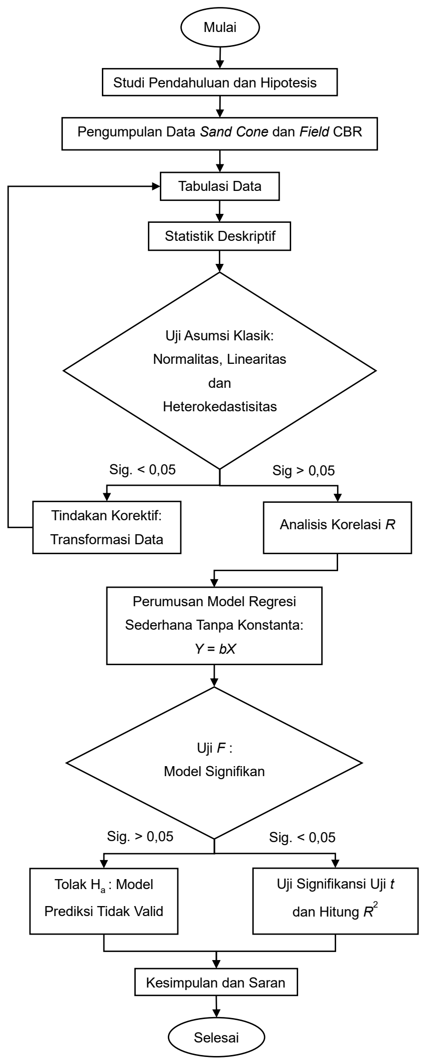

Figure 2. Research Flow Diagram

Data collection was focused on areas that have been marked in blue in Figure 3.

Figure 3. Test Area Plan

This study uses one independent variable (*X*) representing the average soil density value obtained from the Sand Cone test for layers 1-7 of the base soil mound. Meanwhile, the dependent variable (*Y*) in this study is the soil bearing capacity value expressed through the Field CBR parameter measured on the surface of the 7th layer. The data was processed using the IBM SPSS Statistics 27 application through three main stages.

The first stage involves testing classical assumptions to validate regression models, including normality tests to assess data distribution, linearity tests to confirm whether variable relationships have significant linear relationships or not, and heteroscedasticity tests. The second stage is a correlation analysis that aims to identify the strength of the linear relationship between the average density value from layer 1 to layer 7 to the Field CBR value. The third stage includes simple linear regression analysis without a constant (regression through the origin) to test the effect of the average density value of the seven layers on the carrying capacity of layer 7, as well as formulate a mathematical model in the form of the equation $Y = bX$. This study uses regression without a constant because it is based on the physical logic of soil mechanics that soil bearing capacity (*Y*) is directly proportional to soil density (*X*), where the theoretical bearing capacity value would be zero if the material has no density.

ANALYSIS AND DISCUSSION

This analysis used 26 test area samples as depicted in Figure 3, which included density data (Sand Cone) layers 1-7 on the same area. The sequence of reclamation subgrade heap work layers from layer 1 to layer 7 is depicted as Figure 4.

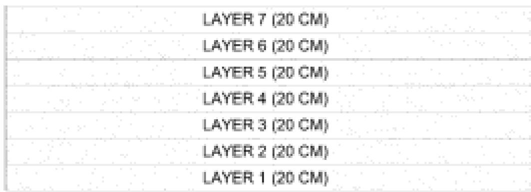

Figure 4. Reclamation Subgrade Stockpile Sequence

Soil Density (Sand Cone) and Soil Bearing Capacity (Field CBR) Data

Data from the test results of Sand Cone layers 1-7 and Field CBR layer 7 subgrade soil conditions, with the specification requirements according to [4] for Sand Cone the specification requirements ≥ 95% and for CBR the subgrade soil condition ≥ 6% are described in Table 1.

Table 1. Results Sand Cone Test and Field CBR test

No	Area	Density Value (*Sand Cone*) Layer 1 - 7 and Bearing Capacity Value (*Field* CBR) Layer 7 (%)								
		Density Layer 1	Density Layer 2	Density Layer 3	Density Layer 4	Density Layer 5	Density Layer 6	Density Layer 7	Average Density Value Layer 1 - 7 (*X*)	*Field* CBR Layer 7 (*Y*)
1	CTT-01	103,95	98,16	103,11	114,35	126,16	114,71	116,49	110,99	11,52
2	CTT-02	113,79	101,41	105,14	100,62	98,44	106,59	106,03	104,57	13,98
3	CTT-04	112,93	104,15	96,26	101,55	99,48	104,60	101,38	102,91	12,61
4	CTT-13	103,89	105,22	107,17	104,63	103,73	108,98	106,95	105,80	13,71
5	CTT-14	102,44	105,12	103,17	105,98	113,33	118,36	117,97	109,48	18,92
6	CTT-17	100,17	114,75	112,68	107,85	105,83	106,53	104,16	107,43	16,45
7	CTT-18	117,87	121,46	106,34	116,49	117,01	115,54	101,64	113,76	16,45
8	CTT-19	112,54	113,22	109,15	114,54	112,60	107,85	108,42	111,19	18,64
9	CTT-23	117,87	121,55	115,71	102,12	97,95	104,36	102,63	108,88	10,69

10	CTT-24	101,95	100,63	107,93	109,71	112,70	111,38	107,76	107,44	13,16
11	CTT-25	103,97	105,34	102,24	102,99	104,48	112,30	101,67	104,71	16,45
12	CTT-28	103,16	109,83	102,36	102,70	102,41	117,23	117,81	107,93	11,52
13	CTT-29	111,67	106,72	104,08	102,76	113,60	129,65	126,97	113,64	14,81
14	CTT-30	103,39	115,46	112,53	98,45	97,25	110,56	112,20	107,12	17,55
15	CTT-34	107,99	104,37	123,97	102,76	106,55	107,93	102,80	108,05	17,55
16	CTT-35	107,69	102,80	107,27	119,71	106,38	111,84	112,09	109,68	13,98
17	CTT-36	101,78	106,61	107,36	108,53	106,44	107,47	104,66	106,12	19,74
18	CTT-37	98,87	101,08	102,82	103,79	130,97	101,06	108,58	106,74	24,13
19	CTT-38	103,04	109,43	108,88	118,22	101,55	100,60	101,96	106,24	7,13
20	CTT-39	104,08	103,30	109,40	97,82	103,97	109,18	106,10	104,84	10,69
21	CTT-40	130,22	106,33	95,53	99,10	100,78	98,83	100,80	104,51	16,45
22	CTT-41	99,63	100,31	104,97	102,18	101,36	105,50	106,86	102,97	14,26
23	CTT-42	102,71	105,19	108,05	102,87	100,89	96,42	97,76	101,99	14,81
24	CTT-43	106,32	103,97	103,91	121,69	117,91	114,01	108,81	110,94	16,45
25	CTT-77	101,11	120,23	109,42	125,94	115,50	114,29	100,64	112,45	17,00
26	CTT-78A	99,70	121,65	99,19	99,04	106,95	102,12	115,21	106,27	14,81
Number of Samples		26	26	26	26	26	26	26	26	26
Min Value		98,87	98,16	95,53	97,82	97,25	96,42	97,76	101,99	7,13
Max Value		130,22	121,65	123,97	125,94	130,97	129,65	126,97	113,76	24,13
Mean		106,64	108,01	106,49	107,17	107,85	109,15	107,63	107,56	15,13
Standard Deviation		7,31	7,12	5,89	7,94	8,61	7,07	6,86	3,24	3,45

It can be seen in Table 1, that the results of the density test (Sand Cone) for layers 1 to 7 show excellent compaction. The average density value for each layer ranges from 106.49% to 109.15%, indicating that it has exceeded the minimum density standard required by [4] which is ≥ 95%.

The independent variable in this study is the average density value (Sand Cone) from layers 1 to 7. The mean value of the independent variable (X) is 107.56%, with a range of 101.99% to 113.76%. The standard deviation value at the average density value (Sand Cone) of layers 1-7 is only 3.24%, which is much lower than the standard deviation of each layer. This shows that the average values of the seven layers can reduce data fluctuations (field noise). This results in more stable and representative input variables that can be used in regression modeling.

The Field CBR value on the surface of the heap (layer 7) has an average value of 15.13%, with a minimum value of 7.13% and a maximum value of 24.13%, indicating that it has exceeded the minimum density standard required by [4] which is ≥ 6%. These values show a significant variation in carrying capacity in the field. The distribution of field CBR data remains within reasonable limits for reclamation backfill materials in the Patimban Port Project Package 6, with a standard deviation of 3.45%.

Classical Assumption Test

Before linear regression analysis test classical assumptions according to [5] is carried out first to ensure that the model meets the BLUE (Best Linear Unbiased Estimator) criteria.

1. Residual Normality Test

The normality test aims to test whether in a regression model, the interference variable or residue has a normal distribution. According to [6] Regression models that are valid for further analysis are those that have normally distributed residual values. This study uses a statistical test One-Sample Kolmogorov-Smirnov with the following decision criteria: if the Asymp. Sig (2-tailed) > 0.05, then the residue is declared to be normally distributed. The results of the normality test using SPSS 27 are presented in Table 2.

Table 2. Result Normality Test (1-Sample K-S)

One-Sample Kolmogorov-Smirnov Test

		Unstandardized Residual
N		26
Normal Parameters[a,b]	Mean	.0000000
	Std. Deviation	3.41368441
Most Extreme Differences	Absolute	.091
	Positive	.081
	Negative	-.091
Test Statistic		.091
Asymp. Sig. (2-tailed)[c]		.200[d]

Based on Table 2 the Asymp value. Sig (2-tailed) is 0.200 > 0.05, so the regression model residue is normally distributed. The assumption of normality is met, allowing for the continuation to the next stage of testing the classical assumption.

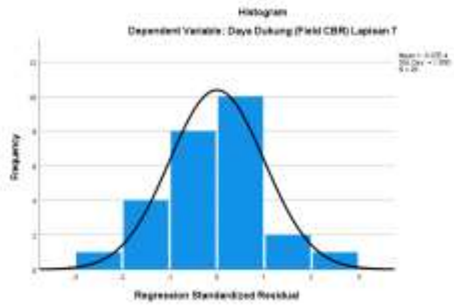

Figure 5. Results Normality Test (Histogram)

Based on Figure 5, the distribution of data frequencies forms a pattern similar to the Bell-Shaped Curve, the data is concentrated in the middle of the distribution, with a relatively balanced slope on the left and right sides. This shows symmetrical properties. Visually, the average density value (Sand Cone) of layers 1-7 and the carrying capacity (Field CBR) of layer 7 from 26 samples followed the normal distribution [7].

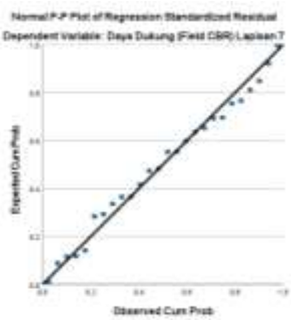

Figure 6. Result Normality Test (P-P Plot)

In the next stage, the Normal Probability Plot (P–P Plot) is used to evaluate normality. The observation points are scattered along a diagonal line, indicating the data meet the normal distribution assumptions according to statistical rules [8].

2. Linearity Test

The linearity test aims to confirm whether the relationship between the free variable, namely the average value of soil density (Sand Cone) in layers 1-7 and the bound variable, namely the soil carrying capacity (Field CBR) in layer 7, is linear or not. The test results using SPSS 27 are presented in Table 3.

Table 3. Results Llinearity Test

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
Daya Dukung (Field CBR) Lapisan 7 * Rata-Rata Nilai Kepadatan (Sand Cone) Lapisan 1-7	Between Groups	(Combined)	50.315	10	5.031	.304	.968
		Linearity	6.991	1	6.991	.423	.525
		Deviation from Linearity	43.324	9	4.814	.291	.966
	Within Groups		247.952	15	16.530		
	Total		298.267	25			

According to Table 3, The significance value (Sig.) in the Deviation from Linearity line is 0.966 > 0.05, meaning that there is a significant linear relationship between the average soil density value (Sand Cone) layer 1-7 (X) and the bearing capacity value (Field CBR) (Y). With the fulfillment of this linearity assumption, the simple linear regression model in this study is considered valid and statistically correct.

3. Heteroscedasticity Test

The heteroscedasticity test aims to detect residual variance disparities between observations in regression models, which should be avoided. The test was conducted through the scatterplot ZPRED (prediction Y) vs SRESID (residue). The results are shown in Figure 7.

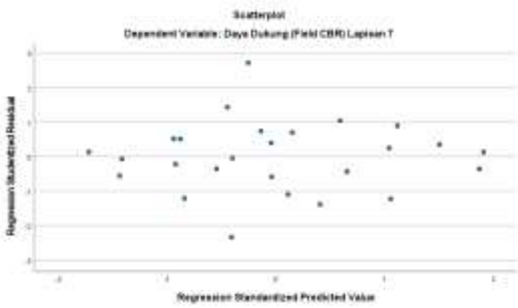

Figure 7. Results Heteroscedasticity Test (Scatterplot)

Based on Figure 7, the data points are randomly scattered above/below the Y=0 axis without any particular pattern (wavy, widening, and narrowing), indicating no heteroscedasticity [9]. The regression model is therefore valid for further analysis.

Table 4. Results Glejser Test

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	3.726	15.155		.246	.808
	Rata-Rata Nilai Kepadatan (Sand Cone) Lapisan 1-7	-.011	.141	-.016	-.079	.938

The results of the glejser test (Table 4) showed that the average soil density value (Sand Cone) of layers 1 to 7 had a significance value (Sig.) of 0.938 > 0.05. indicates that all soil densities of layers 1 to 7 have a significance value (Sig.) > 0.05. This regression model is heteroscedasticity-free, since all significance values > 0.05. This indicates that the regression model is feasible to use to predict the value of the Field CBR [10].

Correlation Analysis

Correlation analysis evaluated the strength and direction of the relationship between the average density value (Sand Cone) of layers 1-7 to the Field CBR layer 7. The strength is measured from the *R* coefficient, the significance of the Sig. *F* Change < 0.05. The results of the multiple correlation of SPSS 27 are shown in Table 5.

Table 5. Results Correlation Test

Model Summary

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate
1	.976[a]	.953	.952	3.41441

Based on Table 5, The correlation value obtained is 0.976, The correlation coefficient interpretation table according to [11]:

Table 6. Interval Coefficient & Correlation Coefficient

Interval Coefficient	Correlation Coefficients
0,00 – 0,199	Very weak
0,20 – 0,399	Weak
0,40 – 0,599	Medium
0,60 – 0,799	Strong
0,80 – 1,000	Very Strong

According to Table 6 the correlation obtained is 0.976, which according to [11] the value is between 0.8 to 1 with a very strong level of relationship.

Simple Linear Regression Analysis Without Constant (Regression Through the Origin)

This simple linear regression analysis without a constant aims to test the mathematical relationship between the average density value (Sand Cone) of layers 1-7 as an independent variable and the Field CBR value as a dependent variable in the Patimban Port Project Package 6. Based on the results of data processing using SPSS 27 presented in Table 7.

Table 7. Results of Simple Linear Regression Test Without Constant

Coefficients[a,b]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	Rata-Rata Nilai Kepadatan (Sand Cone) Lapisan 1-7	.141	.006	.976	22.611	<,001

Based on Table 7, the results of the simple linear regression analysis without a constant (regression through the origin) show a regression coefficient (*B*) of 0.141. This shows that the average density value (Sand Cone) of all layers of the heap (layers 1-7) contributes significantly to the bearing capacity of the surface. Specifically, any 1% increase in average density will increase the Field CBR by 0.141%. Based on the Unstandardized Coefficients column (*B*) in Table 8, the multiple linear regression equation is formulated as follows:

$$Y = 0.141\ X$$

Significance Test (*F* Test)

The *F* test is used to measure the significance of the influence between soil density (Sand Cone) and soil carrying capacity (Field CBR) [12].

Table 8. Results F Test (ANOVA)

ANOVA[a,b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5960.14	1	5960.1	511.240	<,001[c]
	Residual	291.455	25	11.658		
	Total	6251.59[d]	26			

The results of the *F* test in Table 8 were obtained *F*-calculation = 511,240 with a significance level of 0.001 < 0.05, it can be concluded that the average density value (Sand Cone) of layers 1-7 has a statistically significant influence on the Field CBR value. This condition shows that the carrying capacity of the soil in this reclamation project is simultaneous and integrated, where the surface strength (Field CBR) is obtained from the cumulative density of all layers of the underlying deposits, not just the density (Sand Cone) of the upper layer. This shows that, in accordance with the planned design criteria, consistent compaction quality from layer 1 to layer

7 forms a stable soil structure capable of withstanding the load [13]. Based on the results of the F test, it shows that Hypothesis zero (H_0) is rejected, which means that the alternative hypothesis (H_a) is accepted.

Analysis Results *t* Test

The t-test compares the significance value (Sig.) with a significance level of 0.05 (α = 5%).

Table 9. Hasil Uji t

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	Rata-Rata Nilai Kepadatan (Sand Cone) Lapisan 1-7	.141	.006	.976	22.611	<,001

The results of the *t*-test in Table 9 show that the average density value (Sand Cone) of layers 1–7 (*X*) has a t-value of 22.611 and a significance level of 0.001 < 0.05, the average density of all layers of the backfill has a significant and significant influence on the soil carrying capacity (Field CBR) of layer 7 (*Y*). The bearing capacity of the surface depends not only on the individual layers, but also on the cumulative contribution of the entire thickness of the subgrade stack layer (layers 1–7). The theory of stress distribution in soil states that the surface strength (Field CBR) reflects the rigidity of the support zone, which serves to transfer the load from the surface to the deeper layer [14].

Coefficient of Determination (R^2)

The determination coefficient was applied to evaluate how strong the model is in explaining the variation in soil carrying capacity (Field CBR).

Table 10. Results Determination Coefficient Test

Model Summary

Model	R	R Square[a]	Adjusted R Square	Std. Error of the Estimate
1	.976[a]	.953	.952	3.41441

According to Table 10, the *R* Square value is 0.953. Based on these results, it can be concluded that the average density value (Sand Cone) of layers 1-7 (*X*) has an effect of 95.3% on the variation in the Field CBR value of layer 7 (*Y*). Meanwhile, the remaining 4.7% was influenced by other factors outside the study.

Discussion

This section integrates statistical findings with field geotechnical phenomena, comprehensively answering the formulation of the problem and the objectives of the research.

1. Analysis of Correlation and Significance of Layer Depth

Based on statistical analysis, the correlation coefficient (*R*) = 0.976, which shows a very strong positive relationship between the average soil density value (Sand Cone) of the 1st layer to the 7th layer and the soil carrying capacity value (Field CBR) of the 7th layer. This finding indicates that the carrying capacity of the soil in the Patimban Port Project Package 6 is not formed directly from the top layer alone, but is the result of the contribution of all layers of the backpile. The results of the *t*-test showed that the t-value was 22.611 and the significance level was 0.001 < 0.05, the average density of all the layers of the backfill had a significant and significant influence on the soil carrying capacity (Field CBR) of layer 7 (*Y*). In accordance with the principles of soil mechanics, The theory of in-ground stress distribution states that the surface strength (Field CBR) reflects the stiffness of the support zone, which serves to transfer the load from the surface to the deeper layers [14] According to [15] during the CBR Field test, the load exerted by the piston forms a stress influence zone that resembles a voltage ball that spreads into the soil mass.

The density of this "support zone" is the main determinant of the amount of soil resistance to piston penetration. Meanwhile, the significance of the average density value (Sand Cone) of layers 1-7 in this subgrade soil condition reflects the important role of the foundation in providing a stable support reaction for the entire tension ball structure on it, thus preventing excessive settling due to load [16].

2. Interpretation of the Regression Model

The research continued by evaluating a simple linear regression model without a constant (regression through the origin) to answer the second research question. The resulting models of data processing are:

$$Y = 0{,}141\ X$$

Referring to the results of the *F* test, a significance value of 0.001 was obtained, which is statistically far below the threshold of α = 0.05. This indicates that the Alternative Hypothesis (H_a) is accepted and the Zero (H_0) Hypothesis is rejected, the results show that the average variation in the density value (Sand Cone) of layers 1-7 of the pile has a significant relationship with the Field CBR value in layer 7 in this study sample.

Technically, these results show that the seven layers of the backfill in the subgrade soil conditions simultaneously exert a significant influence on the bearing capacity of the surface. This finding is reinforced by an R^2 (R Square) value of 0.953, which suggests that the 95,3% cumulative density of the entire stack layer is a factor that explains the variation in the Field CBR value.

CONCLUSION

Based on the findings of the research and discussion on the effect of the average value of soil density (*Sand Cone*) layers 1-7 on the soil carrying capacity value (*Field* CBR) of layer 7 *of subgrade* soil deposits in the Patimban Port Project Package 6, it can be concluded that:

1. There is a very strong and positive correlation between the average density value (*Sand Cone*) of layers 1-7 and the bearing capacity (*Field* CBR) of the surface (layer 7), as evidenced by the correlation coefficient (R) = 0.976. The higher the average density of the pile, the greater the bearing capacity of the surface.
2. The average soil density value (Sand Cone) of layers 1-7 dominated the influence on Field CBR, with R^2 = 0.953 (95.3%). Through simple linear regression without a constant (regression through the origin) the equation is produced:

$$Y = 0.141\,X$$

A 1% increase in average density increases the CBR Field by 0.141%.

Further research is recommended to examine the 4.7% of other factors outside the model that could potentially affect the soil bearing capacity in reclamation areas, such as particle size distribution characteristics (soil gradation), water saturation levels, and the influence of soil improvement materials. Moreover, to enhance the accuracy, precision, and statistical validity of the predictive model, future studies are suggested to expand the test area coverage to obtain a more representative field data distribution.

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