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A STATISTICAL APPROACH TO DCPT DATA IN DETERMINING SUBGRADE PARAMETERS FOR ROAD PAVEMENTS

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Abstract

This study examines the characteristics of the road base layer in pavement construction using a statistical method based on Dynamic Cone Penetration Test data. The subgrade condition must be accurately assessed to avoid premature pavement failure, such as cracking and settlement. Field investigations were conducted at a number of sites with various types of soil. However, due to access restrictions, only two main sites were tested. Consequently, this paper presents a local preliminary analysis rather than a broad regional one. The results show that the subgrade has low load-bearing capacity, with CBR values between 1.56% and 2.48%. The upper part of the soil, down to 50 cm depth, is generally softer than the lower layers, as observed during the tests. SPSS was used to analyze the data, which showed a very strong correlation between DCPT and CBR values. The correlation coefficient (R) was 0.999 and the R-Square value was 0.998. The regression equation, $CBR = 149.668 - 32.557(DCPT)$, shows that CBR values decrease with increasing penetration values. These results indicate that the subgrade in the study area is poor. Stabilization or further compaction is suggested before pavement construction. The regression model developed in this study is for a particular site and it is suggested that the model be validated using other data sets to check its performance at other sites.

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Introduction

Road infrastructure is a critical enabler of economic growth and the movement of people and goods between places (Alfaries et al., 2026). In real-world applications, the performance of a road surface is largely governed by the condition of the subgrade, as this layer is the first to bear the load of vehicles (Ahmed et al., 2024). If the parameters of the subgrade are not identified with sufficient accuracy, a number of problems can arise even in the early stages, such as cracking, rutting, or even loss of bearing capacity (Suhendik et al., 2022). Because of that, understanding subgrade characteristics becomes one of the key aspects in pavement design (Said Jalalul, 2013). One method that is often used in field investigations is the Dynamic Cone Penetration Test DCPT (Xia et al., 2020). This method is quite practical in the field, relatively affordable, and able to provide a quick picture of soil strength variation with depth (Siemann et al., 2026). The results from DCPT are usually linked with other parameters, such as CBR or soil density (Garcia et al., 2024). However, the data obtained in the field rarely come out perfectly consistent (Benz Navarrete et al., 2022). Differences in soil layers, site conditions, and even testing factors often cause noticeable variation in the results (Kim et al., 2022).

In many cases, the analysis of DCPT data is still carried out using simple approaches, for example by taking average values or selecting certain representative data (Oyelami et al., 2024). While this approach is easy to apply, it does not always capture the actual condition of the soil, especially when the data spread is quite wide or contains outliers (Patrick et al., 2019). Because of this the meaning might not be very correct which can make the design not very trustworthy (Sabri et al., 2018). This is the place where using a method is useful because it allows us to examine the data in a more detailed way. This is the place where using a method is useful because it allows us to examine the data in a more detailed way (Opuni et al., 2017). Using analysis we can look at the data more closely. We do not look at the average. With analysis we also consider how the values spread out and how much they differ from each other (Jarushi et al., 2024). Parameters like standard deviation or coefficient of variation show how consistent the data is (Salgado & Yoon, 2003). Statistical techniques also help identify and remove the data that is not very representative. Consequently, the results are more reliable (Yogaturida Isnaini et al., 2019). Software such as SPSS can make this process easier, especially if you have a lot of data (Song et al., 2026). This tool allows to perform the analysis step by step from a basic description to more complex tests such as correlation and regression (Liu et al., 2026). The use of software for statistical analysis along with field data for the evaluation of sub grade parameters in road pavement design is likely to be better (Polo-Mendoza et al., 2024). But the use of statistical methods in the analysis of DCPT is not very common, especially in local studies in Indonesia (Onyelowe et al., 2019). Former studies have predominantly employed empirical relations while neglecting the variability of data (Kulkarni et al., 2010). This is an indication that there is still a gap that needs to be closed, particularly in terms of improving the reliability of data interpretation (Waruwu et al., 2021).

Yet another factor that needs to be considered is that the nature of soil conditions in Indonesia is usually very diverse (Okonta et al., 2024). The variation in soil characteristics can occur with depth, but also at small-scale horizontal distances (Abbondati et al., 2021). Variations like clay, silt, sand, or gravel mixtures will of course affect the soil response to loading. (Chin et al., 2020). In practice, the values of the DCPT are sometimes used directly with no additional checking, although the data distribution might not be normal (Sofronova et al., 2019). This could lead to biased conclusions (Kaliky et al., 2024). Thus, more extensive statistical analysis including normality test, correlation, and regression is essential to provide an insight into the association of DCPT values with subgrade properties (Warsiti et al., 2020). is, so the interpretation is not only based on one number but also depends on the reliability of the data and the The comments in describe how the code works in detail (Nugroho & Satibi, 2022). In addition, the statistical procedures may also help to identify changes in soil layers by changes in penetration values, which can be difficult to detect just by looking at the raw data (Othman & Abdelwahab, 2023). This is

very important in defining the interface between the layers of soil (layering), which are often difficult to see using only raw DCPT data, or even just by eye (Harahap et al., 2023). With the aid of statistics, changes in the trend values of penetration can be interpreted as indicators of variation of soil type or state, thus enabling soil layer parameters determination to be more systematic and more quantifiable (Fakhri & Wibowo, 2024). Processing power availability is also cited as reinforcing this approach. Ordinarily, it not only makes analysis faster, but also reduce the number of errors that could be brought by manual calculation (Oktary & Apriyanti, 2017). Statistical software also speeds up calculations and eliminates human error in data processing. Here, the use of software-based statistical analysis becomes very relevant for the application of more data-driven decision making process for road pavement design (Kusuma et al., 2017).

Nevertheless, challenges persist, particularly those tied to variations in methodology and the ways results are interpreted (Adawiyah et al., 2023). In the absence of a more uniform approach, comparing the findings of one study with those of another can prove difficult (Soehardi & Dwi Putri, 2024). As such, this study additionally seeks to develop a clear and well-organized statistical analysis workflow for handling DCPT data (Alnabawi et al., 2025). In light of these challenges, this research is essential for closing the gap between field testing methods and more scientific approaches to data analysis (Tan et al., 2016). The statistical approach employed is anticipated to enhance accuracy in identifying subgrade parameters without depending directly on bearing capacity parameters, instead highlighting the characteristics of the data itself (Sitinjak et al., 2022). The findings of this study are expected to contribute not only theoretically to the advancement of geotechnical analysis methods, but also practically to assisting planners and practitioners in enhancing the quality of pavement design (Putri Wilis et al., 2024).

Research Methods

Statistical Analysis and Interpretation Criteria

SPSS was used to perform the statistical analysis in order to investigate how Dynamic Cone Penetrometer (DCPT) values relate to California Bearing Ratio (CBR) values. A simple linear regression analysis was performed between DCPT as independent variable (X) and CBR as dependent variable (Y). The statistical results were interpreted using the coefficient of determination (R^2), correlation coefficient (R), F-statistic, t-statistic, significance value (p-value), and Standard Error of the Estimate. The R value was used to represent the strength of the linear relationship between the variables. As per Evans (1996), the absolute correlation coefficient was classified as very weak (0.00–0.19), weak (0.20–0.39), moderate (0.40–0.59), strong (0.60–0.79), and very strong (0.80–1.00). The R^2 value represents the proportion of the variance in CBR that is explained by DCPT within the regression model, and is expressed as a percentage by multiplying R^2 by 100. The F-statistic was used to test the overall significance of the regression model, and the t-statistic was used to test the significance of each individual regression coefficient. A significance level of $\alpha = 0.05$ was adopted, where $p < 0.05$ denotes a statistically significant result and $p \geq 0.05$ denotes a statistically non-significant result. The Standard Error of the Estimate indicated the average magnitude of prediction error between the actual and predicted CBR values. These criteria were established before the regression results were interpreted to provide a consistent framework for categorizing and communicating the statistical findings.

This study was carried out on a road segment in the selected study area which is known to possess varying soil conditions. The two DCPT testing sites were intentionally selected based on engineering judgment and initial site observations, rather than by random or systematic sampling. Selection was based on visible changes in soil, indications of soil layer variation, accessibility of test sites, and representation of prevailing subgrade conditions for pavement design (Li et al., 2026). The exact location is not disclosed for confidentiality reasons, but the study site is characterized by a patchy distribution of soils. The relief of the study site varies from almost level to gently rolling, typical for road construction sites. According to preliminary field observations,

the soil conditions vary from fine-grained to coars-grained materials (Setiawan et al., 2024). In view of heterogeneity of the subgrade, within the study area, two DCPT test points were selected as the location pairs. The pair of points were located at two different points along the section of road subject to study, in order to capture potential variability in soil. Each test point was analyzed separately, and the results between the two points were evaluated in terms of comparing penetration resistance and subgrade conditions. Due to the fact that the study was limited to two DCPT sites, the results were considered as a site-based evaluation and were not indicative of all soil conditions available in the project area (Fetrati et al., 2024).

The study was carried out in several stages: preparation, field data collection by using DCPT, data processing, and finally statistical analysis by SPSS. Testing in the field was conducted in relatively stable meteorological situations to limit the disturbance from external factors such as increment soil moisture due to rain, which might affect the final results. Two DCPT probing stations were selected within the study area along the investigated road segment on the basis of soil differences. The two points were considered as characteristic for the studied segment because they were taken at two different positions in order to catch possible variations of the subgrade along the road. However, since the study area may involve mixed soil types, the two points cannot be assumed to represent all soil conditions within the larger project site. Therefore, the findings were considered as results of the road section-specific evaluation. To facilitate the presentation of the study site, satellite image from Google Earth was used as a visual guide. This is intended to give a general view of the site and yet not too close to the site. Further, as the images also depict how the two sampling points are spaced, the accompanying explanations are easier to follow. The spatial representation of the study area is depicted in Figure 1.



Figure 1. Research Location

The above image shows the study area based on the satellite image. The highlighted region indicates the location of the two DCPT tests. The selected test sites were located on the road segment under study so as to represent variation in subgrade conditions in the adjacent locations. The site was selected based on ease of access to the test sites and for the contrasting soil conditions along the studied reach. Accordingly, the results of these two sites are to characterize the subgrade of the study road segment and not for serving its surrounding. As well, this gives a broad view of the site and can be used to help indicate the location of the test points to make the study area and field work more understandable.



Figure 2. DCPT Device

The instrument used in the investigation was a DCPT set, shown in Figure 2. This device is used to estimate soil penetration resistance in situ. The DCPT consists of several components such as penetration rod, a cone at the tip, a hammer rotated as the falling weight and a handle with a locking mechanism which allows the tool to be locked in place during tests. The steel sampling rod can be extended for greater depths of testing. At the end of a rod a cone with a standard angle is attached which is used to penetrate the soil. In the course of test the hammer is continuously falling from a constant height to have a uniform impact. The primary data is the number of blows obtained per a specific depth. In simple terms, the DCPT works by correlating the number of blows with the depth of penetration. More blows indicate denser or stronger soil. The information obtained from this test are then used to determine soil bearing capacity and the nature of the sub soil layers. Since it is quite simple to perform in field, doesn't require much costs and can produce results in a short period of time, this method was chosen. Furthermore the DCPT results can be correlated with other parameters which make them suitable to be further processed with SPSS when assessing subgrade conditions for road pavement.

Research Results and Discussion

DCPT Analysis

This study describes the DCPT data processing to be able to characterize the soil response to dynamic penetration at different depths. This test enables an assessment of the energy versus penetration relationship, which provides an immediate indication of soil resistance in the field. Soils that are easier to penetrate require less blows, and the opposite is true for soils that are difficult to penetrate. The results of the DCPT test responses are arranged systematically to facilitate easy reading and interpretation. All penetration stages (from surface to maximum depth of test) are recorded with the associated number of blows. From the initial readings, a number of parameters are calculated among which the total penetration, the DCPT value (in mm/blow), and the CBR value estimated. These parameters is important since provide greater insight into variation of soil strength with depth.

Close inspection of the data will reveal whether the soil layers are fairly uniform or whether there are layers at certain depths which are different. Small variations in penetration values can indicate differences in the composition of the soil, while larger variations can indicate transitions between layers. Therefore, the data must be presented in a tabular format, as it allows each parameter to be easily observed and compared over the depths. In addition, the DCPT data presented here are the basis of the rest of the analysis in this paper. These values will then be used to evaluate subgrade conditions and to perform a statistical analysis using SPSS. In this way, the

data are interpreted not only based on what is directly observed, but also through a more systematic analytical process. The DCPT test results for Point 1 are given in Table 1 below.

Table 1. DCPT Result for Point 1

n	D (cm)	Cum. No of blow	AD (cm)	SPP (cm)	Cumulative penetration (mm)	DCPT	Log CBR	CBR%
1	0	0	0	0	0			
2	11.5	1	11.5	11.5	115			
3	18.5	2	7	18.5	185	99	0.19	1.56
4	28.1	3	9.6	28.1	281			
5	39	4	1,9	39	390			
6	49.5	5	10.5	49.5	495			
7	50.2	6	0.7	50.2	502			
8	61.3	7	11.1	61.3	613			
9	64.5	8	3.2	64.5	645			
10	66.2	9	1.7	66.2	662	69.6	0.39	2.48
11	69.2	10	3	69.2	692			
12	78.3	11	9.1	78.3	783			
13	80.6	12	2.3	80.6	806			
14	90.5	13	9.9	90.5	905			

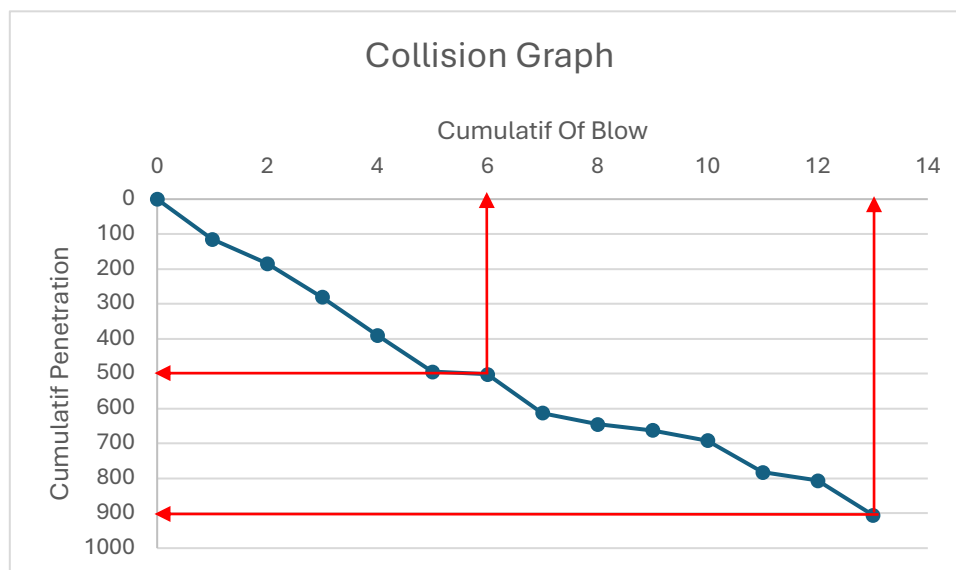


Figure 3. Penetration Diagram point 1

The graph in Figure 3 shows the number of blows as a function of total penetration depth. From the trend, penetration increases quite rapidly at the beginning of the test when the number of blows is still small. This indicates that the top layer of the soil is relatively softer and is easier to penetrate. However, the rate of penetration begins to decline as the depth increases. It can be seen that the same depth needs much more blows than in case of the first layer. This scenario indicates higher soil density or strength in the bottom half. Overall the graph shows that

the soil is not completely uniform. The depth to the top layer and the bottom layer differ as well, although these changes occur gradually.

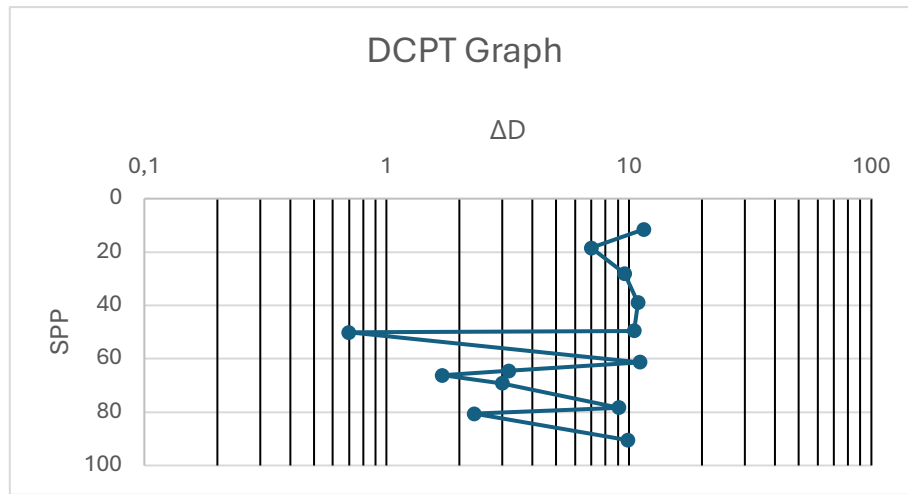


Figure 4. Graph of ΔD versus depth at point 1

The DCPT graph in Figure 4 illustrates the variation of penetration value per blow (ΔD) with soil depth. The values of ΔD do not show a consistent trend with depth but vary at different depths. Higher ΔD values indicate a relatively soft soil layer and lower values indicate a denser soil layer. The two DCPT locations show a generally similar trend, although some depths show some differences. These differences show that the subgrade is not entirely homogeneous over the studied part. Nevertheless, the two profiles are sufficiently similar (the difference between the two locations is within the range determined in the field investigation) to be compared in the analysis. The differences in soil response may be due to variations in soil composition and layer conditions with depth. Therefore, the variation between the two locations was considered when establishing the relationship between DCPT and CBR. The proposed correlation should consequently be interpreted within the range of soil conditions represented by the two investigated locations.

Table 2. DCPT Result for Point 2

n	D (cm)	Cum. No of blow	AD (cm)	SPP (cm)	Cumulative penetration (mm)	DCPT	Log CBR	CBR%
1	0	0	0	0	0			
2	9.8	1	9.8	9.8	98			
3	17	2	7.2	17	170			
4	20.5	3	3.5	20.5	205			
5	24.6	4	4.1	24.6	246			
6	32.2	5	7.6	32.2	322			
7	40.5	6	8.3	40.5	405			
8	51.4	7	10.9	51.4	514	72.69	0.37	2.34
9	60.7	8	9.3	60.7	607			
10	66.3	9	5.6	66.3	663			
11	75.7	10	9.4	75.7	757			
12	83.2	11	7.5	83.2	832			
13	89.1	12	5.9	89.1	891			
14	94.5	13	5.4	94.5	945			

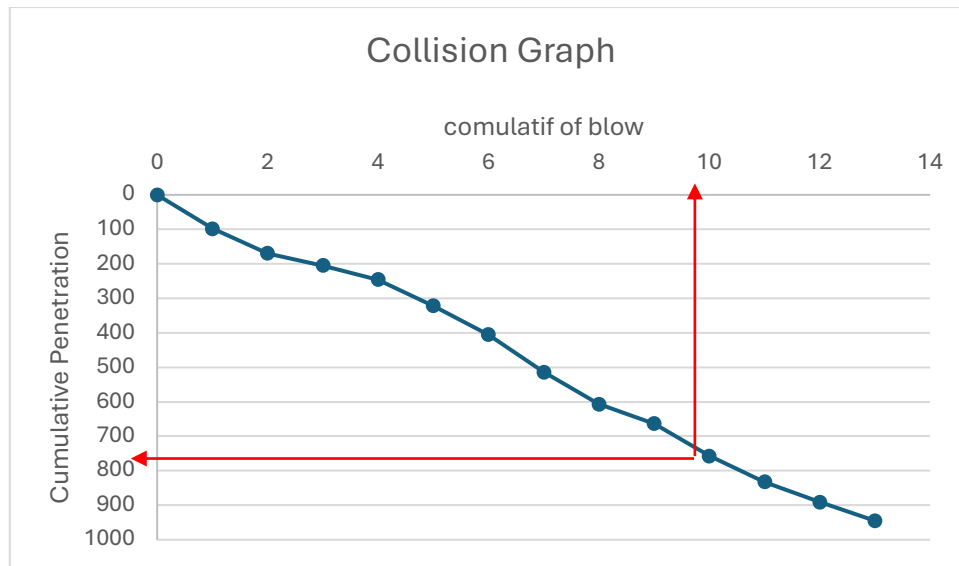
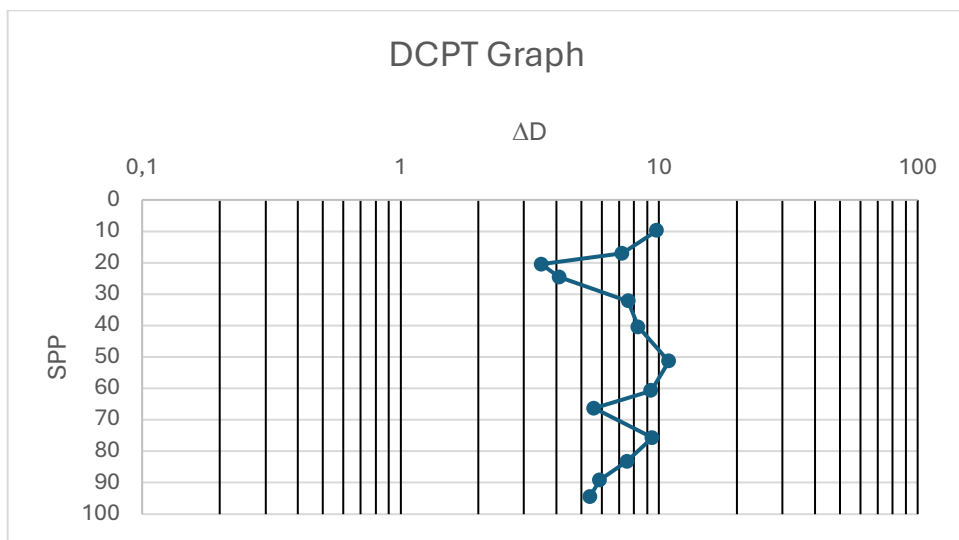


Figure 5. Penetration diagram point 2

In Figure 5, (Collision Graph) shows the relationship between the cumulative number of blows and the cumulative penetration depth. This graph indicates that as the number of blows increases, the penetration depth also increases. The pattern tends to rise gradually, indicating that the soil can still be penetrated progressively as the impact energy increases. Initially, penetration occurs more rapidly, while at greater depths, the penetration rate begins to slow down. This indicates that the upper soil layer is relatively softer compared to the denser layer beneath it.

Figure 6. Graph of ΔD versus depth at point 2

The graph in Figure 6 (DCPT Graph) shows the relationship between the penetration value per blow (ΔD) and depth (SPP) at Point 2. The ΔD values vary at different depths, with some layers showing higher values and others showing lower values. These changes indicate that the soil resistance is not the same throughout the depth of the tested layer. A similar variation was also observed at the other DCPT location, although the magnitude of the changes was not exactly the same. This indicates that the subgrade conditions at the two locations have some differences in their layer characteristics. However, the differences observed in the DCPT profiles were taken into consideration when comparing the two locations and developing the DCPT–CBR relationship.

Therefore, the proposed correlation is considered applicable to the range of subgrade conditions represented by the two investigated locations and should be interpreted with consideration of the observed soil variability.

The results obtained in this study show that the CBR values at both test points are consistently below 3%, indicating poor subgrade conditions. This finding is in line with the study by Ristiawan et al. (2020), which states that soils with CBR values below 5% generally require improvement before being used in pavement structures. In terms of the relationship between DCPT and CBR, an inverse trend is observed, where higher penetration values are associated with lower CBR values. A similar pattern was also reported by Bahan et al. (2024), although the correlation obtained in this study ($R \approx 0.999$) appears to be higher. The fairly strong correlation could be linked to the comparable pattern seen in the DCPT and CBR data collected from the two locations that were investigated. The two locations were chosen deliberately at different points along the road segment under study, based on initial field observations, ease of access, and the variations noted in soil conditions and layering. As a result, the two locations offer a foundation for characterizing the local subgrade conditions and for investigating the DCPT–CBR relationship within the segment studied. Nevertheless, since only two investigation points were available, the findings cannot be taken as representative of the whole broader study area, especially in places where spatial heterogeneity may be greater. The difference noted between Point 1 and Point 2 suggests that the subgrade is not entirely uniform, yet the generally consistent link between DCPT and CBR offers a basis for establishing a site-specific correlation. Accordingly, the regression relationship derived in this study should be understood within the range of soil conditions covered by the two investigated locations, and further investigation points would be needed to confirm its validity for a larger or more heterogeneous area.

SPSS Analysis

Based on the data collected from the two investigated locations, the proposed DCPT–CBR equation exhibits a very strong correlation, with an R value of 0.999 and an R^2 value of 0.998. Nevertheless, these values should not be taken to mean that the equation carries the same level of confidence when it is applied to other locations. The confidence in the proposed equation is restricted to the soil conditions covered by the present investigation. Consequently, the equation is recommended as a supporting tool for preliminary pavement design and subgrade assessment, rather than as the only basis for final design decisions. Prior to applying the equation in engineering practice, additional DCP tests should be carried out at several locations along the investigated road segment in order to capture possible spatial variations in soil conditions. Since this study relied on only two investigation locations, a specific minimum number of DCP tests cannot be determined from the present data. Instead, the needed number should be determined according to the length of the road section, the subgrade variability, and the confidence level. Further independent field validation is also recommended prior to use of the equation over larger and different regions.

Table 3 presents the Model Summary, where the R value is 0.999, indicating a very strong linear relationship between DCPT and CBR for the studied dataset. The R -Square value of 0.998 indicates that the DCPT variable explains 99.8% of the variance in CBR in this regression model. The Adjusted R -Square value of 0.996 also shows that the model retains a high explanatory value after adjustment. Meanwhile, the Standard Error of the Estimate is 1.04855, indicating the average magnitude of prediction error in the model. These statistical indicators demonstrate that the regression model provides a strong fit to the data obtained from the two investigated locations. However, the statistical performance should not be interpreted as sufficient evidence of direct engineering applicability. The model was developed from a limited number of investigation locations, and its reliability may be affected by local soil characteristics and spatial variability. Therefore, the equation should be regarded as a site-specific relationship and should be further validated using additional field data before being applied to pavement design in other locations.

Table 3. Results of the Determinant Regression Analysis

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change
1	0.999	0.998	0.996	1.04855	0.998

The ANOVA results in Table 4 show an F-value of 473.818 with a significance value of 0.029. Since the significance value is lower than 0.05, the regression model is statistically significant at the 5% significance level. This result indicates that the linear relationship observed between DCPT and CBR is statistically significant for the dataset analyzed in this study. However, statistical significance does not by itself demonstrate that the model is universally applicable for engineering design. The model should therefore be interpreted together with the limited number of test locations, the observed soil variability, and the site-specific nature of the data. For practical pavement design, additional DCPT investigations and independent validation are recommended before using the regression equation as a design parameter.

Table 4. ANOVA Significance Test

Model		Sum of Squares	df	Mean Square	F	Sig
1	Regression	520.942	1	520.942	473.818	0.029
	Residual	1.099	1	1.099	-	-
	Total	522.041	2	522.041	473.818	0.029

In the Coefficients table 5, the following values were obtained:

Constant = 149.668

DCPT Coefficient = -32.557

Thus, the resulting regression equation is:

$CBR = 149.668 - 32.557 (DCPT)$

Table 5 shows that the DCPT coefficient is negative, indicating an inverse correlation between DCPT and CBR. This means that higher DCPT values, which indicate less resistance and a relatively softer soil, are associated with lower CBR values. Conversely, lower DCPT values are an indication of higher penetration resistance and are associated with higher CBR values. The calculated t-value of -21.767 and the significance level of 0.029 (<0.05) shows a statistically significant partial relationship between DCPT and CBR within the studied dataset. However, this statistical relationship should be interpreted with caution, as the empirical relationship was based on only two DCPT investigation locations. The locations were selected to represent local variations in subgrade conditions along the investigated road section, not to be a statistically representative sample of the entire study area. Therefore, the results shown here only provide a preliminary site-specific indication of the DCPT-CBR relationship. Additional DCPT investigation locations and independent CBR measurements would be required to increase the sample size, better account for spatial variability, and provide stronger statistical evidence before the developed relationship can be applied to a larger or more heterogeneous region.

Table 5. Significance Test for the Coefficient

Model		Unstandardized B	Coefficients Std. Error	Standardized Coefficients Beta	t	Sig
1	(Constant)	149.668	3.238	-	46.223	0.014

X1	-32.557	1.496	-0.999	-21.767	0.029
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Conclusion

The results of this study clearly demonstrate that using the proper statistical analysis with SPSS helps to interpret DCPT data more precisely and consistently. The model used is considered reliable for the prediction of subgrade conditions because of the very strong correlation between DCPT and CBR values. The field tests, which were carried out at two separate locations, show that the soil in the study area generally has low bearing capacity. This is also reflected in the CBR values, which are between 1.56% and 2.48% and therefore fall into the poor subgrade category. In addition, the upper soil layer of 0-50 cm is generally softer than the underlying layers, which may be influenced by soil moisture and compaction conditions. The analysis also shows an inverse relationship between DCPT and CBR values. Lower CBR values are usually associated with higher penetration values, which indicate weaker soil conditions. This trend is always present in the data. In summary, the findings of this study suggest that the current soil conditions are not yet adequate for direct use as road pavement construction. Therefore, improvement measures are needed, such as soil stabilization, better compaction or the addition of a supporting layer. These are necessary to ensure that the pavement structure functions correctly in the long term.

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