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Original Article

Evaluation of Pavement Deterioration using In-Situ DCP-CBR Tests and Comparative to the Remolded Optimum State

Lucky Caroles

Lecturer, Postgraduate Program at Hasanuddin University, Makassar City 90245, South Sulawesi, Indonesia

Lucky.Caroles@psp4.org

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Abstract - *Road damage refers to the state where the functional and structural pavements are no longer effective in providing optimal service to vehicles crossing the road. The design of construction planning and the pavement created are heavily influenced by traffic circumstances and the sorts of vehicles that will cross a road. A road pavement structure's performance will eventually degrade over time. This phenomenon arises due to cyclic loads on the pavement structure generated by the weight and vibration of vehicles passing over it. This study was carried out as a case study of road deterioration in South Sulawesi Province, Indonesia, precisely around the site of the wind power plant's entrance in Sidrap Regency. The CBR value of the soil at the site was obtained using Dynamic Cone Penetrometer Testing following ASTM D6951. At the same time, the CBR value of remolded laboratory samples was employed under ASTM D1883. The soil used as the material for the laboratory CBR sample was excavated from the DCP testing points. According to the findings of this study's investigation, there was severe damage to the road pavement layer, which might have been caused by the dry-wet cycle. The soil shrinks and becomes brittle during the dry season, while in the wet season, the soil swells. The soil should be protected from weather impacts to overcome and avoid additional damage. Provided that the soil is categorized as cohesive, it should be able to maintain the load for a longer service period.*

Keywords - *California Bearing Ratio (CBR), Dynamic Cone Penetrometer (DCP), Road Deterioration, Road Pavement.*

1. Introduction

The performance of a road surface structure will degrade over time. This phenomenon is caused by the cyclic stresses placed on the pavement structure due to the weight and vibration of moving vehicles. This drop in performance may appear as a loss of the pavement's engineering capabilities or complete deterioration in the worst-case situation. This issue is sometimes referred to as road deterioration. Road deterioration may result from a multitude of factors. Under the asphalt, one of the reasons is the degradation of the current pavement layer [1]. The layer's essential state will eventually deteriorate with time, whether in the subgrade, base, or subbase layer. The CBR value is the primary indicator of the strength of the soil to handle traffic loads. Comparing the penetration load of the test material to a preset standard load yields the CBR value [2]. The standard CBR values are applied differently for the base, sub-base, and subgrade layers. The closer the surface, the higher the required CBR value [3]. This research was conducted as a case study of road degradation in Indonesia's South Sulawesi Province in the vicinity of the entry road of the wind power facility in Sidrap Province. From the construction of the power plant to the present, this road segment has been crossed by many heavy trucks. As a consequence, the condition of the pavement on these roads is often evaluated to predict additional significant damage and plan the necessary repairs.

2. Literature Review

The literal definition of road damage is when the functional and structural pavements no longer provide optimum service to cars crossing the road. Traffic conditions and the types of vehicles crossing a road substantially impact the design of construction planning and the pavement developed [5][6]. Comparable to other buildings, whose construction is based on the loads that will occur in line with the building's function. The building of roads must withstand the level of traffic without failing [7] [8].

The road pavement is a layer of road surface set between the subgrade layer and the wheel of a vehicle that serves to provide service to transportation facilities. It is anticipated that no significant damage will occur throughout its service life. Consequently, the pavement must satisfy the appropriate specifications. It is essential to acquire and prepare road paving materials [9].

The CBR value is the most important criterion for pavement layers. CBR (California Bearing Ratio) is a California Department of Transportation-developed soil strength parameter measurement. This test involves penetrating a soil sample at a predetermined rate while measuring the loads in the sample. Therefore, the subgrade or other materials used to create the pavement may be tested for their strength [10, 11]. CBR testing is used to determine soil strength following ASTM D1883. After being compared to what is required in the specifications, the result of the soil's capacity will be used as a reference to determine whether or not it needs to be stabilized [12].

CBR testing compares a material's penetration load to that of standard material at the same depth and rate of penetration. The CBR value is computed for 0.1-inch and 0.2-inch penetrations, and the results of the two computations are assessed using ASTM D1883, with the highest value being used [13, 14].

The CBR value is the percentage ratio of the pressure required to penetrate the remolded soil sample with a piston having a circular cross-section of 3 inches2 moving at a rate of 0.05 inches per minute to the strength required to penetrate a certain standard material[15]. This CBR evaluation aims to ensure the CBR value when compacted using varied water content [16]. The CBR experiment yields a value that would compute the minimum pavement thickness over a layer with a predetermined CBR value. In new road construction, untreated soil, embankment soil, or excavated soil compacted to 95 percent of the maximum density is used as the subgrade [17].

CBR testing can be performed in a laboratory or on-site. The laboratory-compacted CBR sample was frequently used to benchmark the soil's optimum or ideal state. One method used to obtain the undisturbed soil CBR value is Dynamic Cone Penetrometer (DCP) testing [17, 18].

The Dynamic Cone Penetrometer (DCP) is a minimal instrument consisting of a metal rod with a 60-degree cone hammered into unrestrained pavement structure and soil subgrade with an 8-kg metal sledgehammer at a drop height of 575mm. As numerous correlations linking the DCP index (mm/blow) to CBR value have been found, the DCP has become widely employed in many regions of the world to evaluate the in-situ strength of soil subgrade and pavement layers [19][20]. The calculation of DCP will be presented in the Methodology.

Recently, road users' behavior has significantly contributed to pavement failure. Every road is classified based on its structure and the volume of traffic that may travel across it [21, 22]. For instance, grade 3 roadways in Indonesia would almost likely get destroyed if they had to accommodate heavy vehicles or cargo trucks or if they had to endure weights that were above the roadway maximum tonnage boundaries [23]. Here's where the weighbridge comes into play since it serves as a vehicle weight controller, ensuring that the vehicle does not violate the weight capacity of the transportation infrastructure categories being traveled and the vehicle's load capacity [24, 25].

The pavement structure should stay strong since it serves as the base for any forces operating on the surface. The subbase, base, and surface course are the three primary stages of road construction (pavement) [26, 27]. The surface layer of the road pavement is tightly connected to the movement of traffic vehicles. Approximately 80% of roadways in Indonesia typically utilize a flexible surface layer composed of asphalt mixtures [21, 28].

3. Methodology

This research compared the original, undisturbed state of the field to the ideal parameters obtained by a routine compaction test. First, DCP CBR testing is conducted in the field at a predetermined location. The CBR DCP test area site is dug to get a soil sample. The test point and sample excavation point serve to distinguish between soil samples. Field-collected soil samples are then analysed in the laboratory to establish their soil qualities. After completion, the soil is compacted under standard technique, with the maximum dry content weight at the ideal water content. When the dry density value and the ideal water content are attained, the data is then used to re-compact the soil into a laboratory CBR sample. A laboratory CBR test establishes the soil's optimal CBR value. After complete laboratory CBR testing, the findings are compared to field-collected DCP CBR data. Thus, the difference in CBR value between the laboratory and the field, considered a drop in CBR value due to field loading, is detectable. This research was conducted along the entry route of the wind power facility in Sidrap Regency. Fig. 1 illustrates the location of the research. Using Dynamic Cone Penetrometer Testing following ASTM D6951, the CBR value of the site's soil was determined. While the CBR value of laboratory samples that have been remoulded is used in line with ASTM D1883, the material for the laboratory CBR sample was extracted from the DCP testing locations. The laboratory CBR value is a standard for assessing the pavement's original state. Five sampling locations and five laboratory CBR soil samples extracted from each sampling location were evaluated.

Fig. 1 Location of the study (2P56+64V, Mattirotasi, Watang Pulu, Sidenreng Rappang Regency, South Sulawesi 91661)

The following was the systematic process of field investigation procedures in this study:

1. Assess the current pavement layer in the field using the ASTM D6951 procedure.
2. To get field CBR values, collect and evaluate data from field testing results.
3. Soil samples were taken from the same location as the DCP test.
4. Analyzing the characteristics of soil samples in the laboratory
5. Using the ASTM D698 technique, conduct a proctored test to determine the density and compaction parameters necessary to attain the maximum dry density.
6. The soil sample is remolded into a CBR test specimen in line with the compaction characteristics and density obtained.
7. Perform CBR testing in the lab on remolded samples under ASTM D1883.
8. Analyze the laboratory CBR data that has been collected.
9. Compare field data from undisturbed conditions (CBR In-Situ/DCP) to compacted soil data from optimal conditions (CBR Lab).

The formula used to calculate the CBR value using the Dynamic Cone Penetrometer test with a cone angle of 60 degrees based on ASTM D6951 is as follows [29] [30].

CBR=292/DCP1.12 (mm/blow) (1)

CBR=292/(DCP x 25.4)1.12 (inch/blow) (2)

Except for CL soils with a CBR of less than 10 and CH soils, the formula above applies to all soils. The US Army Corps of Engineers suggests the following equations for varied soils.

CBR=1/(0.017019 x DCP)2 (mm/blow) (3)

CBR=1/(0.432283 x DCP)2 (inch/blow) (4)

Equation (3) and equation (4) designated for CL soils with CBR < 10 and;

CBR=1/(0.002871 x DCP) (mm/blow) (5)

CBR=1/(0.072923 x DCP) (inch/blow) (6)

Equation (5) and equation (6) are designated for CH soils.

Meanwhile, using an ASTM D1883 piston penetration test at a rate of 0.05 inch/min, the following formula was used to compute the laboratory CBR value [15].

CBR (0.1 Inch) = [(Load Dial Reading in 0.1 in penetration x Proving Ring Calibration)/(3 x 1000)] % (7)

CBR (0.2 Inch) = [(Load Dial Reading in 0.2 in penetration x Proving Ring Calibration)/(3 x 1500)] % (8)

4. Result and Discussion

Table 1 illustrates the findings of soil property testing at the CBR DCP testing location, which was completed in the laboratory using soil samples excavated from the field.

Table 1. Properties of the excavated soil sample

Test		Result	
		Value	Unit
Basic Properties:			
Initial water content (w)		55,71	%
Specific gravity (Gs)		2,66	-
Sieve Analysis and Hydrometer:			
a	Sand	35,20	%
b	Silt	34,55	%
c	Clay	30,25	%
Atterberg Limits:			
a	Liquid Limit (LL)	60,76	%
b	Plastic Limit (PL)	46,35	%
c	Plasticity Index (PI)	14,42	%
d	Shrinkage Limit (SL)	26,51	%
Standard Proctor:			
a	Optimum Dry Density, (γd)	1,41	gr/cm^3
b	Optimum Water Content (OMC)	23,94	%
Soil Type : MH			

According to Table 1, the soil examined was of the silt type with high plasticity, denoted by the abbreviation MH in the USCS classification system. This information can be found by looking at Table 1. The soil on the field is very saturated and has a high water content; as a result, it significantly exceeds the maximum density criteria advised.

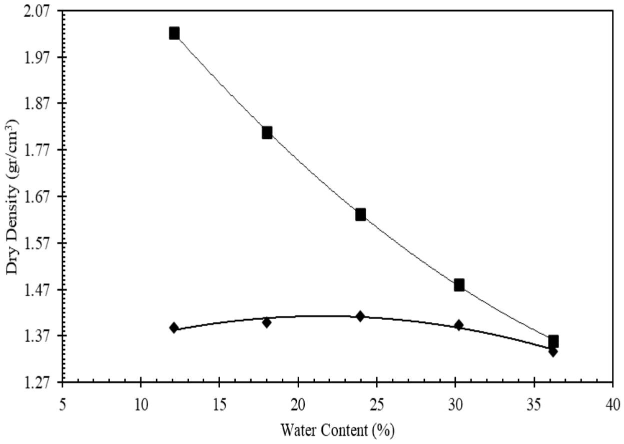

Fig. 2 Correlation of water content and dry density according to ASTM D698

According to Fig. 2, the required water content to attain maximum density is 23.94% of dry soil weight. The standard proctor approach may generate a maximum density of 1.41 gr/cm^3.

If a soil's water content is low, the soil will be hard or stiff and difficult to compress. However, if the water content is increased, the water will serve as a lubricant, making the soil easier to compact and reducing the void space between grains. Because the soil pores are filled with water that cannot be removed by compaction, the density value will drop with high water content. The higher the compaction effort at a slightly lower soil moisture level, the denser the soil. However, if the water content is significant, more compaction effort does not result in denser soil since the pore space is already filled with water. The soil texture is spread at the same compaction effort as the water content of the soil increases.

When soil conditions are drier than the optimal moisture level, the soil tends to develop a flocculated texture. Even while the water content stays the same, the texture becomes more scattered if the compaction effort is increased. For clays compacted on the dry side of the optimal moisture content, expansion is increased, and shrinkage is less.

It results from the flocculated texture, susceptibility to additional water, and a lower reference moisture level for expansion. For soils that are moister than the optimal moisture content, the reference moisture content is so high that only a minor addition is required to raise the saturation degree (Sr) to 100 percent to restrict soil expansion. The shrinkage caused by the high reference water content is logically substantial since the percentage change in water content as the soil dries will be substantial.

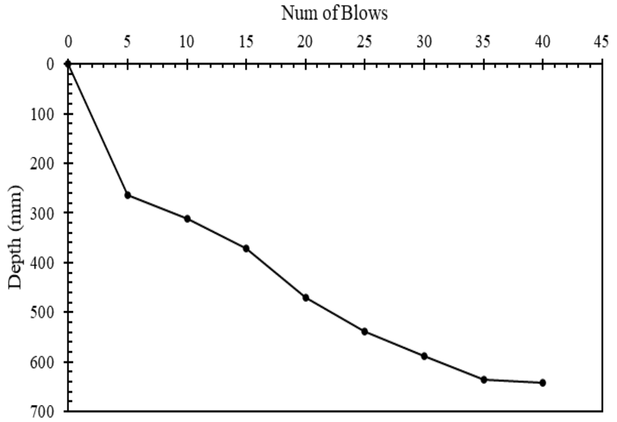

Fig. 3 DCP and depth correlation in sampling point P1

At a sampling point P1, only 40 cumulative blows can be used to penetrate to a depth of 64.3 cm. CBR findings obtained at a depth of 20 cm are relatively low, at only 0.57 percent. At depths ranging from 20 to 60 cm, the average CBR value was 3.13 percent. And at a depth of 64.3 cm, the CBR value is 28.44 percent.

Penetration may only be carried out to a depth of 24.5 cm with 30 cumulative blows at sampling point P2. At a depth of 20 cm, the average CBR value was 3.88 percent. While the average CBR value recorded at a depth of 20 to 24.5 cm is 23.06 percent, the average CBR value measured at a depth of 20 to 24.5 cm is 23.06 percent.

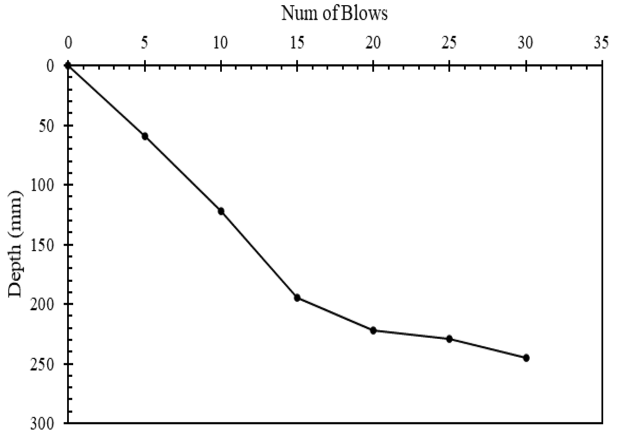

Fig. 4 DCP and depth correlation in sampling point P2

While at sampling point P2, penetration can only be performed to a depth of 24.5 cm with 30 cumulative blows. The average CBR value measured at a depth of 20 cm was 3.88 percent. The average CBR value measured at 20 to 24.5 cm depth is 23.06 percent.

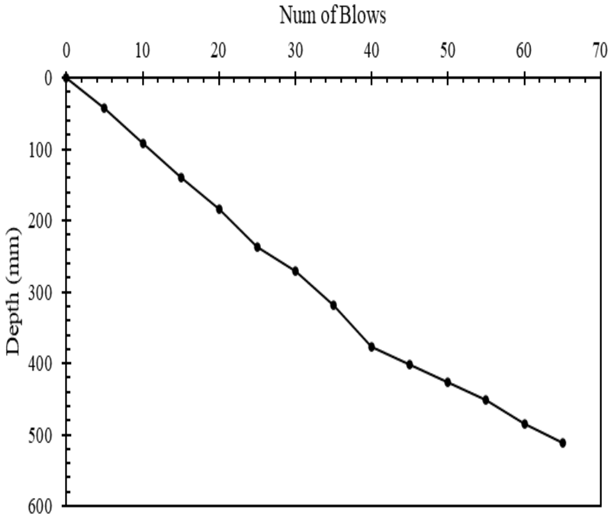

Fig. 5 DCP and depth correlation in sampling point P3

The DCP test was performed to a depth of 51.2 cm at sampling point P3. At a depth of 37.6 cm, the average CBR value measured is 4.44 percent, whereas, at a depth of 13.6 cm below, the average CBR result calculated is 7.31 percent.

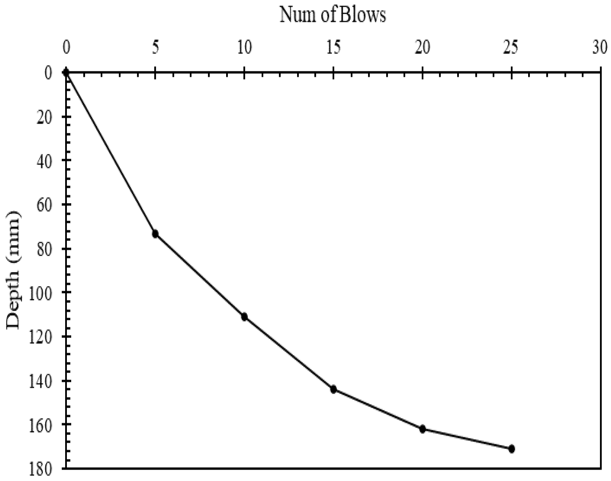

Fig. 6 DCP and depth correlation in sampling point P4

The CBR test was performed to a depth of 17.1 cm at sampling point P4. At a depth of 7.3 cm, the average CBR value obtained is 2.39 percent, whereas, at a depth of 0.9 cm below, the average CBR value obtained is 18.20 percent.

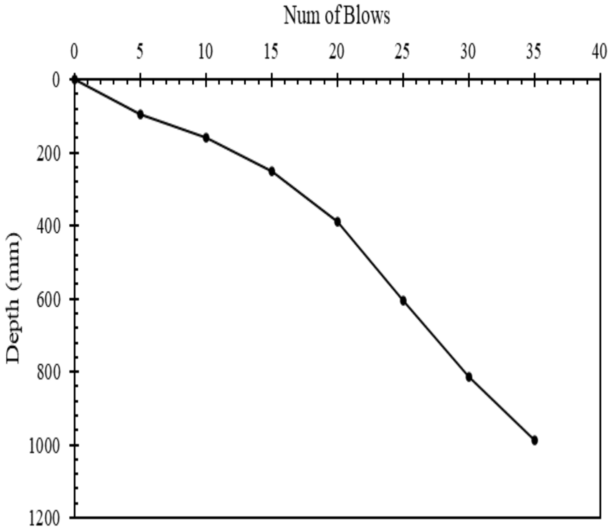

Fig. 7 DCP and depth correlation in sampling point P5

The worst circumstance occurred in the DCP test at sampling point P5 when none of the CBR readings surpassed 2.77 percent at a depth of over 100 cm. At this fifth point, the average CBR value is only 1.80 percent. Among the sample points, this one has the weakest circumstances.

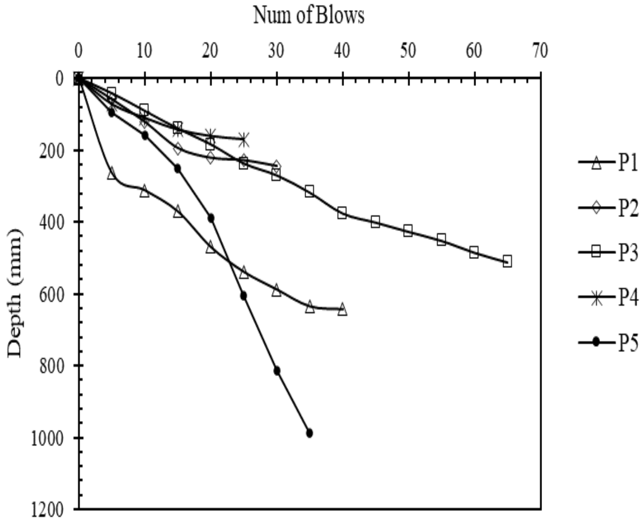

Fig. 8 DCP and depth correlation in all sampling point

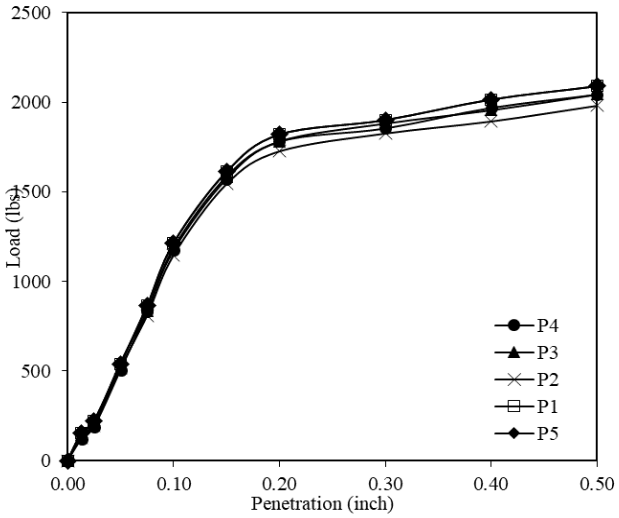

Fig. 9 Load and penetration correlations on the remolded CBR sample

Fig. 9 shows that the soil behavior is uniform across all sample locations. Following laboratory re-compaction, CBR values ranged from 38.40 percent to 40.47 percent. The material under test is most likely the embankment previously used as the subbase layer. Consequently, the CBR values consistently meet Indonesian standards (Sub Base: 20 percent CBR).

The outcomes of DCP field experiments, on the other hand, demonstrated the opposite outcome. The CBR value achieved falls significantly short of the road construction criteria and specifications. The CBR value of the soil was dropped by more than 90% at sample point 5. Meanwhile, the CBR of a meter deep soil at sampling locations remained lower than the road CBR value criteria.

Table 2. Recapitulation of CBR and DCP test results

Sample	CBR (%)	CBR DCP	Reduction
P1	40.47	28.44	29.72%
P2	38.40	23.06	39.95%
P3	39.60	7.31	81.53%
P4	39.57	18.20	54.01%
P5	38.97	1.80	95.38%
Average CBR Value	39.40	15.76	60.00%

It might be induced by the vehicle load and impacted by the soil's wet-dry cycle [31], according to the features of the undisturbed sample. Indonesia has two seasons yearly, as is widely known (Tropical). During the dry season, the earth shrinks and becomes brittle. There are also a lot of cracks in the ground surface. Meanwhile, the soil swells during the rainy season. It can cause the compacted soil structure to be disrupted, resulting in a reduction in the soil's mechanical capacity and engineering attributes [32, 33]. It is a common occurrence in Indonesia. Because of the extent of the season's effect, the prevalence of soft soil deposits on practically all Indonesian islands, and the absence of protection against road pavement constructions in Indonesia, many identified roads fail to finish their service period [34].

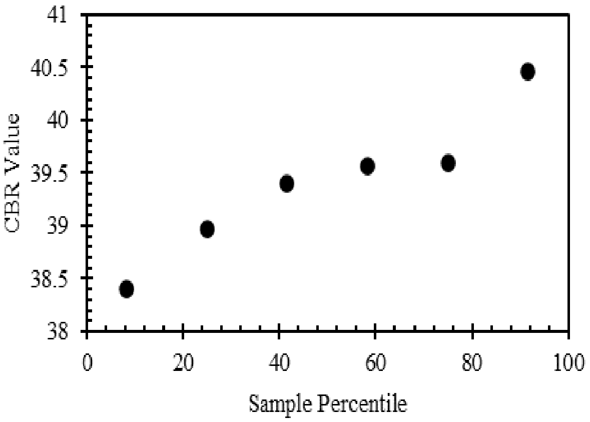

Fig. 10 Normal Plot Data Distribution

Fig. 10 depicts the trend of the association between the CBR value in the field and the CBR value in the laboratory as determined by linear regression. The R2 score of 0.10373 suggests that the data distribution is satisfactory. 0.022 is the coefficient value that emerges between the two data regressions.

This research shows that by comparing the findings of the Undisturbed condition test with those of the ideal condition, the deterioration of the CBR value, which reflects the level of road detection, can be discovered and assessed. This procedure is specified by some standards and may be used in various settings with similar characteristics. This approach may be used to identify deterioration to the road foundation layer in an effective and precise way.

The CBR loss was recognized, particularly as it was associated with this study's findings. These findings may be used as a guide for road preservationists to restore damaged roads, offer protection, and avoid additional damage in other areas using the same manner.

5. Conclusion

Measuring the number of CBR in the field and comparing conditions to the optimal conditions of the same soil can be used to detect road deterioration. Changes in the primary parameters utilized in road planning and design are immediately assessed using this technique. As a result, the difference in values obtained may be immediately utilized as a reference level of reduction in the road foundation's designed capacity. This analysis revealed that the bearing capacity of the road foundation at the study location had significantly decreased. It is most likely due to a regular wet-dry cycle in tropical areas such as Indonesia. As a result of the expansion and shrinkage events, the structure of the soil will change. The soil shrinks, become brittle during the dry season, and expands during the rainy season. To overcome and avoid future damage, the soil should be protected from weather impacts; if the soil is cohesive, it should be able to support the load for a longer period. As a result of the findings of this research's investigation and analysis, it is strongly suggested that the road foundation at the study site be strengthened. To improve the longevity of road pavement, it is also necessary to consider protection against the seasons.

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References

[1] S. A. Sarna, G. Goh, and D. Perić, "Identifying Acceptable California Bearing Ratio (Cbr) Value for Kansas Subgrades using Pavement Rutting Data," pp. 333–342, 2022, Doi: 10.1061/9780784484067.034.

[2] V. P.-A. I. J. of C. Engineering and Undefined , "the Effect of Limestone and Fly Ash on Clay Stabilization on Cbr and Soil Compressive Strength:(Access Road for the Wellpad Construction Project in Ujung," Adri.Journal.Or.Id, vol. 7, 2022, Accessed: May 03, 2022. [Online]. Available: Http://Adri.Journal.Or.Id/Index.Php/Aijce/Article/View/71

[3] E. S. Encinares, J. Krizzia, and D. Encela, "Prediction of California Bearing Ratio (Cbr) using Dynamic Cone Penetrometer (Dcp) for Soils From Second District in the Province of Sorsogon," Uijrt.Com, vol. 03, pp. 2582–6832, 2022, Accessed: May 03, 2022. [Online]. Available: Https://Uijrt.Com/Articles/V3/I5/Uijrtv3i50003.Pdf

[4] S. Satvati, B. Cetin, and J. C. Ashlock, "Development of Prediction Models for Mechanistic Parameters of Granular Roads using Combined Non-Destructive Tests," *Lect. Notes Civ. Eng*., vol. 164, pp. 113–126, 2022, Doi: 10.1007/978-3-030-77230-7_10.

[5] E. Schnebele, G. Cervone, and N. Waters, "Road Assessment After Flood Events using Non-Authoritative Data," *Nat. Hazards Earth Syst. Sci.*, vol. 14, no. 4, pp. 1007–1015, 2014, Doi: 10.5194/Nhess-14-1007-2014.

[6] V. Baskaran, C. Subash Raj, R. . Subbu Sankar, and K. Blessy, "the Influence of Cbr Value on the Cost of Optimal Flexible Pavement Design," *Sustain. Agri, Food Environ. Res*., vol. 12, no. 1, 2022, [Online]. Available: Https://Doi.Org/10.7770/Safer-V12n1-Art2780

[7] A. Sidess, A. Ravina, and E. Oged, "A Model for Predicting the Deterioration of the International Roughness Index," *Int. J. Pavement Eng*., vol. 23, no. 5, pp. 1393–1403, 2022, Doi: 10.1080/10298436.2020.1804062.

[8] P. Anbazhagan, S. Srinivas, and D. Chandran, "Classification of Road Damage Due To Earthquakes," *Nat. Hazards,* vol. 60, no. 2, pp. 425–460, 2012, Doi: 10.1007/S11069-011-0025-0.

[9] W. Sas and A. Gluchowski, "Application of Cyclic Cbr Test To Approximation of Subgrade Displacement in Road Pavement," *Acta Sci. Pol. Archit*., vol. 12, no. 1, pp. 51–61, 2013.

[10] L. S. Tommy C. Hopkins, Tony L. Beckham, "Characteristics and Engineering Properties of the Soft Soil Layer in Highway Soil Subgrades."

[11] P. P. Nagrale, A. P. Patil, and S. Bhaisare, "Strength Characteristics of Subgrade Stabilized with Lime, Fly Ash and Fibre," *Int. J. Eng. Res*., vol. 1, no. 5, pp. 74–79, 2016.

[12] D. K. Choudhary and Y. P. Joshi, "A Detailed Study of Cbr Method for Flexible Pavement Design," *J. Eng. Res. Appl.,* vol. 4, no. 6, pp. 239–253, 2014.

[13] I. C. Attah, J. C. Agunwamba, R. K. Etim, and N. M. Ogarekpe, "Modelling and Predicting Cbr Values of Lateritic Soil Treated with Metakaolin for Road Material," *Arpn J. Eng. Appl. Sci*., vol. 14, no. 20, pp. 3609–3618, 2019.

[14] 2015 Adams Et Al., "Effect of Triaxial Geogrid Reinforcement on Cbr Strength of Natural Gravel Soil for Road Pavements," *J. Civ. Eng. Res*., vol. 5, no. 2, pp. 45–51, 2015, Doi: 10.5923/J.Jce.20150502.05.

[15] Astm, "Astm D 1883-16," pp. 1–14, 2018, Doi: 10.1520/D1883-16.1.

[16] V. Chundi, S. Raju, A. R. Waim, and S. S. Swain, "Priority Ranking of Road Pavements for Maintenance using Analytical Hierarchy Process and Vikor Method," *Innov. Infrastruct. Solut.,* vol. 7, no. 1, 2022, Doi: 10.1007/S41062-021-00633-7.

[17] S. Method, L. Soils, R. Method, and D. Method, "Standard Test Method for Cbr (California Bearing Ratio) of Soils in Place," *Astm Stand. Guide*., vol. 04, no. May, pp. 21–24, 2005, Doi: 10.1520/D1883-07e02.

[18] V. George, N. C. Rao, and R. Shivashankar, "Pfwd, Dcp and Cbr Correlations for Evaluation of Lateritic Subgrades," *Int. J. Pavement Eng*., vol. 10, no. 3, pp. 189–199, 2009, Doi: 10.1080/10298430802342765.

[19] A. K. Arshad, E. Shaffie, F. Ismail, W. Hashim, N. L. Mat Daud, and Z. Abd Rahman, "Comparative Evaluation of Soil Subgrade Strength using Laboratory and in-Situ Tests," *Int. J. Civ. Eng. Technol*., vol. 9, no. 7, pp. 1184–1191, 2018.

[20] D. R. S. Kumar, A. S. Ajmi, and B. Valkati, "Comparative Study of Subgrade Soil Strength Estimation Models Developed Based on Cbr, Dcp, and Fwd Test Results," *Iarjset*, vol. 2, no. 8, pp. 92–102, 2015, Doi: 10.17148/Iarjset.2015.2820.

[21] J. U. D. Hatmoko, B. H. Setiadji, and M. A. Wibowo, "Investigating Causal Factors of Road Damage: A Case Study," *Matec Web Conf.*, vol. 258, P. 02007, 2019, Doi: 10.1051/Matecconf/201925802007.

[22] T. Al-Refeai and A. Al-Suhaibani, "Prediction of Cbr using Dynamic Cone Penetrometer," *J. King Saud Univ. - Eng. Sci.*, vol. 9, no. 2, pp. 191–203, 1997, Doi: 10.1016/S1018-3639(18)30676-7.

[23] S. G. Shaikh, D. U. Mahajan, M. N. S. Shaikh, and A. P. Wadekar, "Scientific Study of Asphalt Road Surface Distress and Their Role in the Design of Flexible Pavements," *Int. J. Eng. Trends Technol.*, vol. 70, no. 1, pp. 220–232, 2022, Doi: 10.14445/22315381/Ijett-V70i1p227.

[24] S. V Pandey, "Local Road Damage Due To Overloading," *Civil Tekno*, vol. 11, no. 58, pp. 1–8, 2013.

[25] I. Wirnanda, R. Anggraini, and M. Isya, "Analysis of the Level of Road Damage and Its Effect on Vehicle Speed (Case Study: Jalan Blang Bintang Lama and Jalan Teungku Hasan Dibakoi)," *J. Tek. Civil*, vol. 1, no. 3, pp. 617–626, 2018, Doi:10.24815/Jts.V1i3.10000.

[26] R. Faisal, Zulfhazli, A. A. Hakim, and Muchtaruddin, "Comparison of the Bina Marga Method and the Pci (Pavement Condition Index) Method in Evaluating Road Damage Conditions," *Teras J.*, vol. 10, no. 1, pp. 110–122, 2020.

[27] H. Yunardhi, "Analysis of Road Damage using the Pci Method and Alternative Solutions (Case Study: D.I. Panjaitan Road Section)," *J. Teknol. Civil*, vol. 2, no. 2, pp. 38–47, 2018.

[28] S. P. Hadiwardoyo, R. J. Sumabrata, and M. A. Berawi, "Tolerance Limit for Trucks with Excess Load in Transport Regulation in Indonesia," *Makara Technol. Ser.*, vol. 16, no. 1, pp. 85–92, 2012, Doi:10.7454/Mst.V16i1.1336.

[29] Astm International, "Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications 1," *Astm Int.*, vol. D6951/D695, no. Reapproved 2015, pp. 1–7, 2015, Doi:10.1520/D695

[30] E. S. Encinares and J. K. D. Encela, "Prediction of California Bearing Ratio (Cbr) using Dynamic Cone Penetrometer (Dcp) for Soils From Second District in the Province of Sorsogon," vol. 03, no. 05, pp. 12–16, 2022.

[31] S. Sakib, M. A. Islam, and M. S. Hossain, "Assessment of the Seasonal and Spatial Variation in Shear Strength of High Plasticity Clay on Highway Slopes using Dcp Tests," pp. 524–533, 2022, Doi: 10.1061/9780784484036.052.

[32] S. F. Badaron and L. Samang, "Experimental Study of Bearing Capacity and Deformation Behavior of Rigid Pavement Subgrade Layers Due to the Effect of Wet-Dry Cycle," pp. 19–26, 2018.

[33] A. Setya, "Andrew Dawson Water in Road Structures Movement Drainage Effects,"

[34] S. I. K. Ampadu, T. D. Arthur, P. Ackah, and F. Boadu, "Construction and Monitoring of the Short-Term Strength Development of A Cement-Stabilized Lateritic Pavement Layer Under Tropical Climatic Conditions," *Lect. Notes Civ. Eng.*, vol. 164, pp. 727–741, 2022, Doi: 10.1007/978-3-030-77230-7_55.