Indonesian Geotechnical Journal, December 2023, Vol 2 (3). Page 179 - 188
DOI: https://doi.org/10.56144/igj.v2i3.72
E-ISSN:2829-7520
https://indonesian-geotechnical-journal.org/index.php/JGI/issue/archive

CBR Correlation with Index and Compaction Properties of Soil

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SUBMITTED 31 August 2023 **REVISED** 30 September 2023 **ACCEPTED** 11 December 2023

ABSTRACT California Bearing Ratio (CBR) is widely used in the design of road to indicate the bearing capacity of subgrade as well as each layer of flexible pavement system. However, the procedure for obtaining the CBR value is often considered as complicated and time consuming, thus; some correlations were developed by previous researchers between the CBR value and index properties such as fine content (w), liquid limit (LL) and plasticity index (PI) of the soil, as well as between the CBR value and compaction properties i.e., optimum moisture content (OMC) and maximum dray density (MDD). This study was conducted to evaluate the applicability of the published correlation on the soil obtained in Palembang and the surrounding areas. In this case, 30 sets of secondary data were collected and selected from past projects. In addition, laboratory tests were conducted on five sets of samples for verification purpose. The laboratory tests include wet sieve to obtain fine content, Atterberg limits to determine soil's plasticity, and standard Proctor test to obtain OMC and MDD. Analysis shows that with modifications, some published correlations could be used to predict unsoaked and soaked CBR values for soils in Palembang. Furthermore, two correlations were developed between the CBR values and compaction properties of the soil based on statistical analysis of the collected data.

KEYWORDS CBR, fine content; plasticity index; optimum water content; maximum dry density.

1 INTRODUCTION

California Bearing Ratio (CBR) is widely used to represent the bearing capacity of subgrade and sub-base soils for the design of flexible pavements. Therefore, the CBR value plays a significant role in road and highway construction (Jayamali, et al., 2018). Several countries have developed or adopted pavement design procedures based on the material's CBR value, including the current design of flexible pavement according to the Pavement Design Manual of the Indonesia Ministry of Public Works and Public Housing (2017).

The CBR values of subgrade can be obtained following ASTM D1883-07 or Indonesian standard SNI 1744-2012. There are two types of CBR for compacted soil i.e., $CBR_{unsoaked}$ and CBR_{soaked}. Obtaining the CBR value in the laboratory is quite complicated and time-consuming, especially the CBR_{soaked}. CBR test is performed on soil samples compacted at optimum condition based on the compaction properties of the soil. ASTM D1883-07 and SNI 1744-2012 stated that the CBR_{soaked} was to be conducted after the compacted soil sample was soaked for 96 hours (4 days).

A number of correlations are found in literature representing the relationships between CBR values and several soil parameters. Most of them relate the CBR with index properties obtained from sieve analysis, Atterberg limits tests, and compaction properties (Katte, et al., 2019). For example, the NCHRP (2001) and Maity et al. (2018) formulas relate the CBR value with fine contents or w (defined as % passing No 200 sieve) and plasticity index (PI). However, Mak & Gofar (2007) showed that for Malaysia soil, the index properties obtained from sieve analysis and Atterberg limit tests have a minor effect on the CBR values, thus they suggested a correlation between CBR_{soaked} with optimum moisture content (OMC) and maximum dry density (MDD) from standard compaction tests. Other researchers found that there is a combined effect of index properties and compaction properties (Agarwal & Ghanekar, 1970; Patel & Desai, 2010, Bassey et al, 2017;). Agarwal & Ghanekar (1970) show that the CBR value was influenced by OMC and liquid limit (LL). Patel & Desai (2010) proposed a number of correlations of CBR with OMC, MDD, and PI for soil in India. Bassey et al. (2017) multiple linear regression analysis on three types of soil in Nigeria shows that different parameters influence the CBR values of different types of soil. For Obiono soil, PI and OMC are the more influential on CBR while OMC and MDD are the more influential on Onna soil, and LL, PI, and OMC can be used to effectively predict the CBR of Oron soil. In Aceh, Indonesia Marwan & Sundary (2012) proposed a correlation between CBR value with Index Plasticity only. The summary of correlations considered in this study is presented in Table 1.

This paper presents the results of a study on the correlation between CBR values (unsoaked and soaked) with index properties i.e., fine content, soil's plasticity, and compaction properties of soil samples obtained in Palembang and surrounding area. Published correlations were evaluated using Data Analysis, and new correlations were proposed based on Multiple Linear Regression Analysis in the Microsoft Excel application.

Table 1. Summary of published correlation between CBR values and soil parameters

No	Researchers	Correlation	Comment
1	Agarwal & Ghanekar (1970)	$CBR = 2 – 16 \, Log \, (OMC)+0.07 \, LL$	India
2	NCHRP (2001)	CBR = 75/(1+0.728($w \, PI$) w and PI in fraction	USA
3	Mak & Gofar (2007)	$CBR_{soaked} = OMC \, (MDD/A)^{20}$ $A = 18.5 – 19.3$	Malaysia
4	Patel & Desai (2010)	$CBR_{unsoaked} = 17.009 – 0.0696 \, PI + 6.296 \, MDD + 0.0648 \, OMC$ $CBR_{soaked} = 47.907 – 0.093 \, PI –$ $18.78 \, MDD – 0.3081 \, OMC$	India
5	Marwan & Sundary (2012)	$CBR_{unsoaked} = -0.990 \, PI + 28.79$ $CBR_{soaked} = -0.673 \, PI + 15.88$	Aceh, Indonesia
6	Bassey et al. (2017)	CBR = -1.656-0.239PI+0.898OMC CBR = -257.843+2.867OMC+128.186MDD CBR =-90.169-0.415LL–0.815 PL–0.581OMC	Ibiono soil Onna soil Oron soil
7	Maity et al. (2018)	$CBR_{soaked} = – 0,001 \, (w \, PI) + 7.116$ w and PI in %	India

2 METHODS

The objective of this study is to develop empirical correlations between the $CBR_{unsoaked}$ and CBR_{soaked} with index and compaction properties of soil samples obtained in Palembang and the surrounding areas. Parameters considered as independent variables are fine contents obtained from wet sieve analysis (passing No 200 sieve size) denoted as w; soil's plasticity obtained from Atterberg limit tests i.e., liquid limit (*LL*), plasticity limit (*PL*), and plasticity index (*PI* = *LL* – *PL*); as well as compaction properties i.e., optimum moisture content (*OMC*) and maximum dry density (*MDD*).

Two types of data were used in this study i.e., secondary data and primary data. The secondary data was collected from past projects in Palembang and the surrounding area (Figure 1). The secondary data was selected carefully by identifying the soil classification and the procedure adopted to obtain each property. Thirty sets of secondary data were used in this study. The primary data was obtained by conducting laboratory tests on five samples scattered within the area shown in Figure 1 for verification purposes.

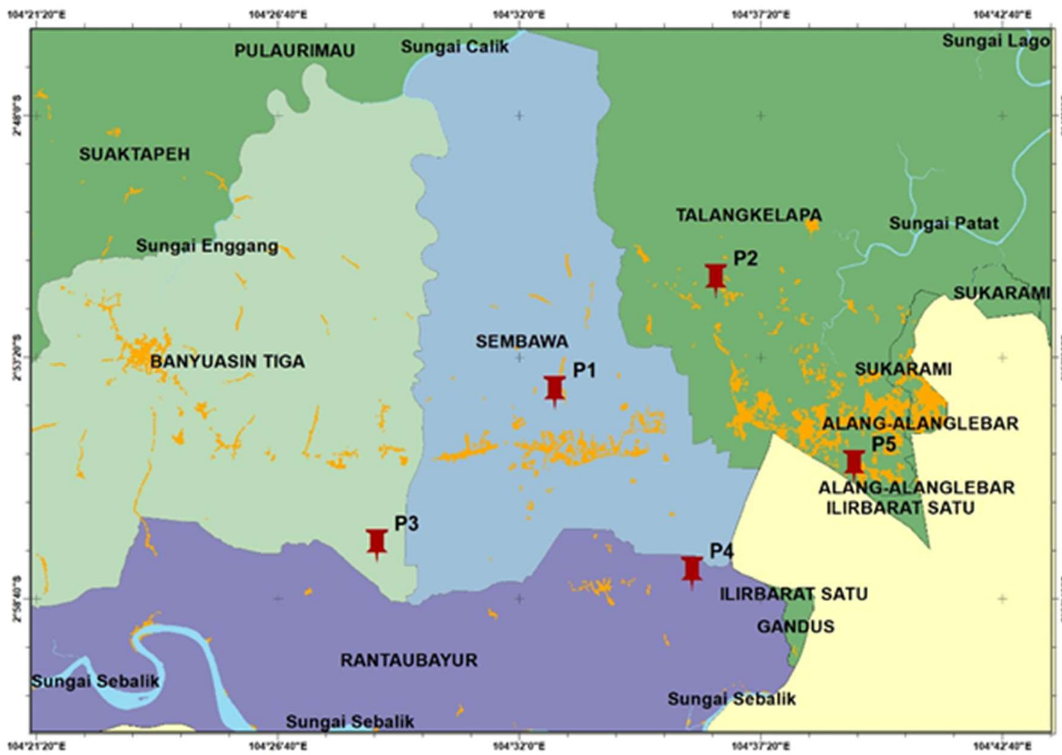

Figure 1. Location of study area and soil sampling.

The validity of the data was ensured by the equal standard procedures used to obtain the data as shown in Table 2. The quality of the data was also evaluated by conducting statistical analysis of each data (*w, LL, PI, OMC,* and *MDD* as well as $CBR_{unsoaked}$ and CBR_{soaked}. The data was then plotted together with the CBR predicted by the relevant published correlations and compared.

Table 2. Summary of published correlation between CBR values and soil parameters

No	Parameter	Test	ASTM
1.	Fine content	Sieve analysis	ASTM D422-63
2.	LL, PL & PI	Atterberg Limits	ASTM D4316-00
3.	Soil Classification		ASTM D2487-00
4.	OMC & MDD	Standard Proctor	ASTM D698-12E1
5.	CBR unsoaked & CBR soaked	CBR Laboratory	ASTM D1883-07

3 RESULTS

3.1 Data Analysis

Table 3 presents the primary and secondary data used in this study. Data No 1 – 30 is secondary data while No 31 – 35 are primary data identified as P1 – P5. The primary data are the results of the laboratory test performed on soil samples collected from 5 locations as shown in Figure 1. Comparison of secondary data with primary data showed that the data used in this study is of sufficient quality; therefore, they can be used together in examining the relationship between CBR values, index properties and soil compaction properties.

Table 3. Data used in this study.

No.	Code	Pass Sieve No 200 (%)	LL (%)	PL (%)	PI (%)	OMC (%)	MDD t/m³	$CBR_{unsoaked}$ (%)	CBR_{soaked} (%)
1	Air Batu	43.94	33.22	13.33	19.89	15.70	1.80	13.21	6.65
2	BR NA 1	58.47	59.21	31.62	27.59	25.47	1.55	11.58	6.05
3	SK.02	59.70	54.02	24.50	29.53	30.12	1.43	9.67	4.75
4	BR. 27	60.84	49.74	32.53	17.20	26.30	1.47	11.58	6.05
5	CF 01	43.94	35.82	14.33	21.49	35.67	1.52	11.54	6.58
6	SK.03	53.92	58.16	32.35	25.81	25.47	1.55	11.24	6.18
7	BR 05	57.80	54.33	31.59	22.74	24.25	1.54	11.15	6.12
8	BR 06	76.85	53.45	21.53	31.92	36.00	1.32	8.22	4.45
9	BRKM 4 (1)	63.26	55.68	30.47	25.21	27.17	1.49	11.07	6.03
10	BRKM 4 (2)	81.42	59.50	27.14	32.36	31.21	1.41	8.72	3.68
11	GL KM 2	53.05	50.84	30.66	20.18	23.28	1.59	12.20	6.24
12	BR SM 3	69.51	61.53	28.71	32.82	31.11	1.39	10.12	4.65
13	TR 02	66.49	34.46	14.19	20.27	18.73	1.71	14.03	6.30
14	TR 03	60.26	51.77	31.83	19.94	25.00	1.56	10.10	6.25
15	BR 32	72.74	55.18	30.81	24.37	26.50	1.47	10.40	6.02
16	TB 1	60.69	64.92	41.91	23.01	29.00	1.38	9.25	4.26
17	KT.1	89.68	38.21	19.16	19.05	27.00	1.41	6.29	4.11
18	KT.2	52.93	38.96	17.27	21.69	24.50	1.51	10.09	4.61
19	SW.1	56.76	29.26	14.91	14.35	22.00	1.56	11.07	6.04
20	SW.2	63.91	54.15	32.55	21.60	21.00	1.55	12.49	5.58
21	CMS	80.52	37.90	19.15	18.75	22.00	1.57	6.55	3.15
22	KCM 1	50.41	60.62	37.62	23.00	25.00	1.51	12.26	6.11
23	KCM 2	57.36	50.55	31.19	19.36	27.00	1.41	12.25	6.05
24	KCM 3	69.18	61.40	35.17	26.23	28.80	1.39	11.75	6.03
25	KM 1	78.83	46.68	27.58	19.10	28.00	1.43	7.18	4.52
26	PG 1	75.00	59.46	29.24	30.22	28.50	1.45	7.30	4.90
27	PG 2	75.00	55.36	26.15	29.21	25.30	1.49	7.98	4.89
28	BR 23	56.57	53.30	31.48	21.82	26.00	1.48	12.56	6.14
29	BR 24	58.84	53.10	31.42	21.68	26.00	1.51	13.15	6.17
30	BR 26	63.40	57.50	33.11	24.39	25.30	1.49	11.78	6.05
31	P1	95.68	49.90	30.6	19.3	32.58	1.39	13.82	6.10
32	P2	84.31	49.73	28.14	21.60	27.89	1.47	10.67	3.18
33	P3	46.67	48.60	30.47	18.13	28.43	1.52	9.46	4.75
34	P4	59.64	36.07	19.15	16.93	25.25	1.55	13.85	7.34
35	P5	59.90	36.60	18.79	17.81	23.75	1.54	11.67	6.08

Evaluation of test data implied that the soil is classified as clay with high and low plasticity (CH and CL according to USCS classification) with a range of LL between 35 and 65%, while PI between 15 and 40%. The percentage of particles passing No 200 sieve is > 40%. Figure 2 shows the positions of the soil classification based on the USCS plasticity chart (ASTM D2487-00).

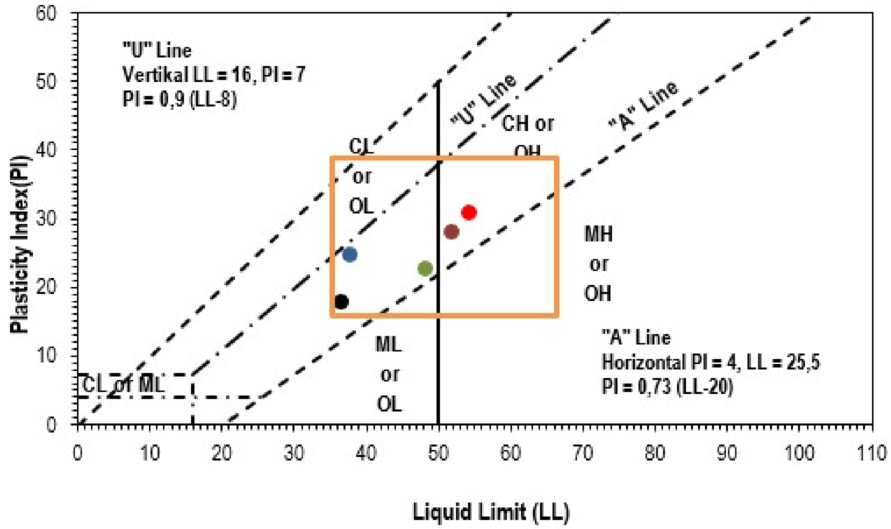

Figure 2. Soil classification based on the USCS plasticity chart.

The statistical analysis of the data used in this study is presented in Table 4. It can be seen from the Table, that the coefficient of variation of all data is below 20%. Statistically, the data is considered uniform if the coefficient of variation is less than 5%. However, for soil properties, the coefficient of variation of 20% is considered good (Kulhawy. 1992). Thus, it can be concluded that the data used in this study is uniform and of good quality.

Table 4. Statistical analysis of the data used in this study

Variable	Mean	Standard Deviation	Coefficient of variation (%)
Fine content (*w*) %	64.50	12.58	19.5
LL %	50.25	9.06	18.0
PI %	23.10	4.50	19.5
OMC %	26.43	4.13	15.6
MDD (t/m^3)	1.50	0.09	6.2
$CBR_{unsoaked}$ %	10.75	2.07	19.3
CBR_{soaked} %	5.54	1.14	20.6
$\frac{CBR_{soaked}}{CBR_{unsoaked}}$	0.52	0.07	14.4

Statistical analysis was performed on the correlation between CBR values and each parameter to look at the effect of the parameter on CBR. Evaluation of the relationship between each data to the value of the $CBR_{unsoaked}$ and CBR_{soaked} results in the trend and the coefficient of determination (R^2) as shown in Table 5. From this Table, we can conclude that the $CBR_{unsoaked}$ could be related with *w*, *w IP*, and *MDD* while the CBR_{soaked} could only be related to the *MDD*.

Table 5. Statistical analysis of the data used in this study

No	Relationship		Coefficient of determination R^2	Trend
1	$CBR_{unsoaked}$	w	0.44	Negative
2	$CBR_{unsoaked}$	LL	0.01	Constant
3	$CBR_{unsoaked}$	$w\ IP$	0.32	Negative
4	$CBR_{unsoaked}$	IP	0.11	Negative
5	$CBR_{unsoaked}$	OMC	0.09	Negative
6	$CBR_{unsoaked}$	MDD	0.26	Positive
7	CBR_{soaked}	IP	0.09	Negative
8	CBR_{soaked}	OMC	0.01	Constant
9	CBR_{soaked}	MDD	0.40	Positive

3.2 Evaluation of Published Correlation

The effect of each parameter on CBR was then compared with that derived from published correlations. Figure 3 shows the effect of the product of fine content and plasticity index (w PI) on $CBR_{unsoaked}$ according to the data and NCHRP (2001) formula. It can be seen from Figure 3 that (w PI) has a negative effect on the $CBR_{unsoaked}$ value; however, the effect on the local soil is less significant as compared to that predicted by the NCHRP formula. Thus. modification to the NCHRP formula is suggested in this study for soil in Palembang. The proposed correlation is as follows:

$$CBR_{unsoaked} = 152/(1+0.0003(w\ PI) \qquad (1)$$

in which the *w* and *PI* are in fractions.

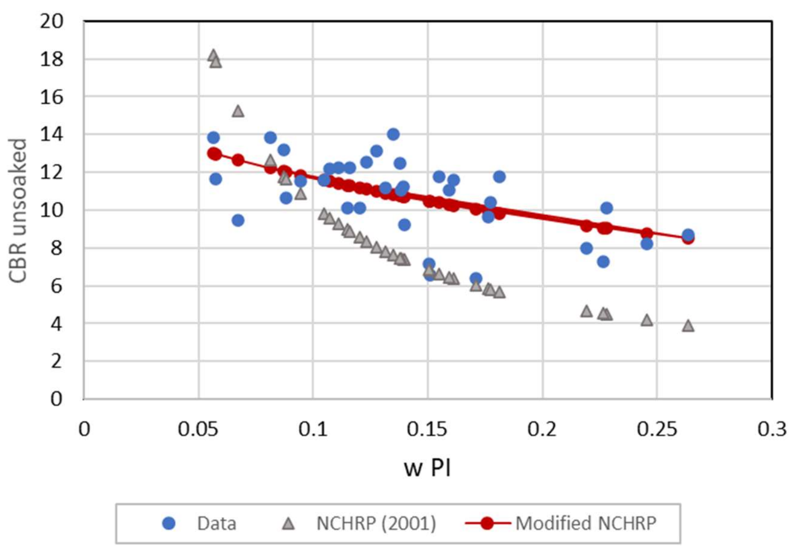

Figure 3. Effect of w PI on $CBR_{unsoaked}$ using Modified NCHRP equation

Similarly, Figure 4 shows that the (*w PI*) has negative effect on CBR_{soaked} according to the data and Maity et al. (2018) formula. The trend is almost similar with the Maity's formula even though the data is quite scattered with a coefficient of determination (R2) of 0.21. Thus. Maity's formula could be used to predict the CBR_{soaked} of soil in Palembang. The proposed correlation is given in Equation 2.

$$CBR_{soaked} = -10\ (w\ PI) + 7.116 \qquad (2)$$

in which the *w* and *PI* are in fraction

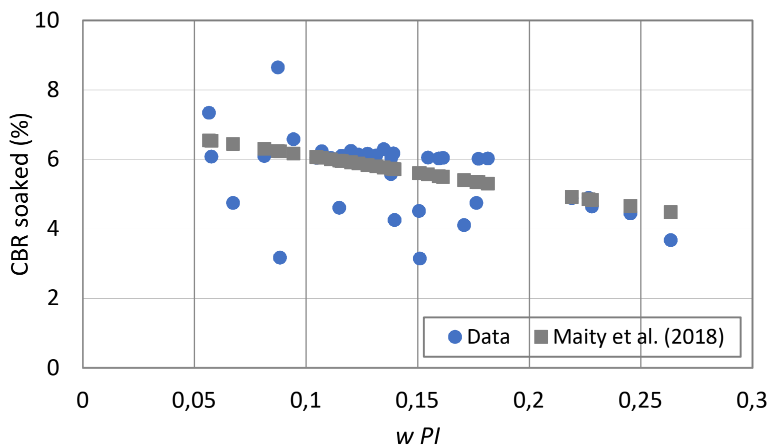

Figure 4. Effect of *w PI* on CBR_{soaked} using Maity et al. equation

Previous studies (e.g., Lakshmi et al., 2016) suggest that both $CBR_{unsoaked}$ and CBR_{soaked} increase with increasing MDD and decrease with increasing OMC. This agrees with the trend show in Table 5. Among the correlations evaluated in this study, only Agarwal & Ghanekar's equation gives the same trend as the data, thus the equation is plotted in Figure 5. By removing the LL term, the modified Agarwal & Ghanekar's equation is more applicable to the soil in Palembang (Eq. 3).

$$CBR_{unsoaked} = 2 - 16 \text{ Log (OMC)} \qquad (3)$$

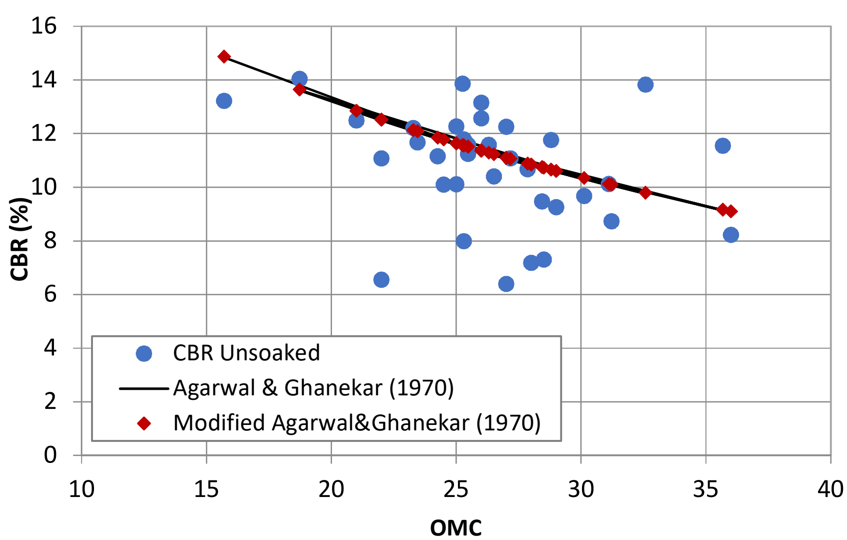

Figure 5. Effect of OMC on $CBR_{unsoaked}$ using Modified Agarwal & Ghanekar equation

Evaluation of Patel & Desai (2010). Mak & Gofar (2007) and Marwan & Sundary (2012) equations showed that the formulas are not applicable for soil in Palembang for different reasons. Patel & Desai equations show the opposite trend of CBR value with respect to MDD and OMC from laboratory compaction tests. Mak& Gofar equations show an exponential correlation while a linear relationship is the more representative of the data used in this study. Marwan & Sundary equations are not suitable because they give a negative value of CBR for a high plasticity index.

3.3 Proposed Correlation

Multivariate statistical analyses were performed on the relationship between the CBR values with MDD. The correlations are given in equations (4) and (5) and plotted in Figure 6. For these equations, the OMC is in % and the MDD is in t/m^3.

$$CBR_{unsoaked}=-10.095+0.077OMC+12.570\,MDD \quad (4)$$

$$CBR_{soaked} = -10.531+0.067OMC+9.555\,MDD \quad (5)$$

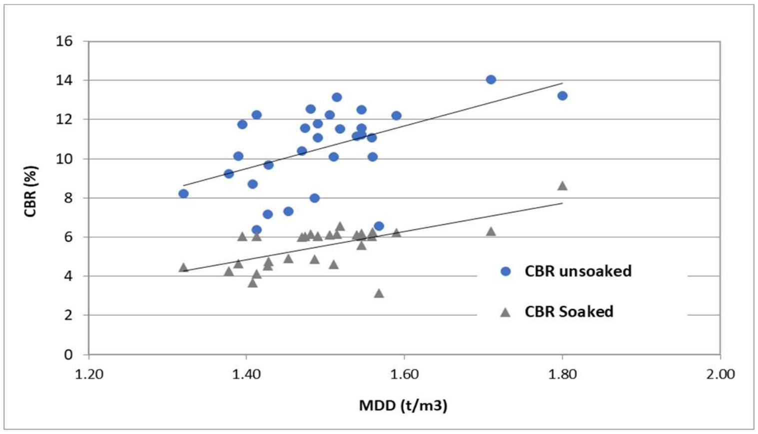

Figure 6. Effect of *MDD* on $CBR_{unsoaked}$ and CBR_{soaked}.

4 DISCUSSION

As shown in Table 3, the combination of secondary and primary data used in this study is quite uniform with a coefficient of variation (CoV) of less than 20% for all variables. This CoV is considered good for Geotechnical data. Evaluation of the relationship between each data to the value of the $CBR_{unsoaked}$ and CBR_{soaked} shows a moderate coefficient of determination with the fine content *w*, product of fine content, and plasticity index *w PI* and maximum dry density *MDD*. Thus, equations can be derived between the CBR value with these parameters.

Of the 8 (eight) empirical formulas analyzed in this study. the modified NCHRP equation (Eq. 1) and Agarwal & Ganekar's equation (Eq. 2) can be used to estimate the $CBR_{unsoaked}$ of soil in Palembang. while Maity et al.'s equation (Eq. 3) can be used directly to estimate CBR_{soaked}. These correlations show the effect of the product of *w PI* on the CBR values.

New correlations (Eq. 4 and Eq. 5) are proposed based on multivariate statistical analysis for the correlation of $CBR_{unsoaked}$ and CBR_{soaked} values based on compaction properties.

5 CONCLUSION

This study aimed to evaluate the applicability of published correlations and to develop new correlations of CBR with index and compaction properties for soil found in Palembang and the surrounding areas. For this study, 30 sets of secondary data and five sets of primary data were used. The soils are classified as clay with low to high plasticity (CL and CH according to USCS). Published correlations were evaluated and three of them can be used for the soil in Palembang with some modifications. In addition. two correlations were developed based on Multiple Linear Regression analysis between the CBR and compaction properties. The proposed correlations (Equations 1 – 5) are valid for the soil used in this research. Care must be taken to apply the correlation for soils from different locations.

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author.

ACKNOWLEDGMENTS

The authors appreciate the service given by CV Geoteknik Pratama in providing the secondary data and laboratory facilities for obtaining primary data.

REFERENCES

ASTM D1883-07. 2007. Standard Test Method for California Bearing Ratio (CBR) of Laboratory-Compacted Soils; ASTM International: West Conshohocken. PA. USA.

ASTM D422-63. 2002. Standard Test Method for Particle–Size Analysis of Soils; ASTM International: West Conshohocken. PA. USA.

ASTM D4318-00. 2000. Standard Test Methods for Liquid Limit. Plastic Limit. and Plasticity Index of Soils; ASTM International: West Conshohocken. PA. USA.

ASTM D854-02. 2002. Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer; ASTM International: West Conshohocken. PA. USA.

ASTM D698-12E1. 2012. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3)); ASTM International: West Conshohocken. PA. USA.

ASTM D2487-00. 2000. Standard Practice for Classification of Soils for Engineering Purposes. Unified Soil Classification System; ASTM International: West Conshohocken. PA. USA.

Bassey, O.B., Ambrose, E.E., & Attah, I.C. 2017. Correlation between CBR Values and index Properties of soils: A Case study of Ibiono. Oron and Onna in Akwa Ibom State. *Resources and Environment*, 7(4), pp. 94-102.

Ministry of Public Works and Public Housing. Directorate General of Highways. 2017. Road Pavement Manual (Revision: June 2017) No 04/SE/Db/2017

Kulhawy, F.H. 1992. On evaluation of static soil properties. In: Seed R.B., Boulanger R.W. (eds) Stability and performance of slopes and embankments II (GSP 31). ASCE. New York. pp. 95–115

Jayamali, K.D., Nawagamuwa, U.P., & Indraratna, B. 2018. Estimation of four-day soaked CBR using index properties. *Australian Geomechanics Journal*, 53 (4), pp. 149-158.

Lakshmi, S.M., Subramanian. S., Lalithambikhai. M.P., Vela. A.M., & Ashni. M. 2016. Evaluation of Soaked and Unsoaked CBR Values of Soil Based on The Compaction Characteristics. *Malaysian Journal of Civil Engineering,*. 28(2), pp. 172-182

Maity. J., Ghosh. S.K., & Hati. S. 2018. Correlation of CBR with Different Soil Properties. *International Research Journal of Engineering and Technology (IRJET),* 5(4), pp. 2081-2084

Mak. W.K., & Gofar N. 2007. California Bearing Ratio Correlation with Soil Index Properties. *Proceedings of the 16th South East Asia Geotechnical Conference*. Selangor Darul Ehsan. 8-11 May.

Marwan & Sundary, D. 2012. Hubungan Nilai California Bearing Ratio dengan Indeks Plastisitas Tanah Desa Neuheun Aceh Besar. *Jurnal Teknik Sipil Universitas Syiah Kuala,* 2(1), pp. 97 - 104

Morrison. J., 2009. Statistics for Engineers: An Introduction. John Wiley 194 p.

National Cooperative Highway Research Program (NCHRP) 2001. Design for New and Rehabilitated Pavement Structures. Final Document. In: Properties. West University Avenue Champaign. Illinois

Patel, R.S., & Desai, M.D. (2010) CBR Predicted by Index Properties for Alluvial Soils of South Gujarat. Indian Geotechnical Conference. GEOtrendz 2010, pp. 79-82