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Techno-Science Research Journal

Prediction of California Bearing Ratio with Soil Properties of Road Subgrade Materials in Cambodia

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Received: 12 May 2023; Accepted: 15 August 2023; Available online: December 2023

Abstract: *California Bearing Ratio (CBR) value has been widely used to evaluate pavement foundation characteristics. To minimize the effect of human errors, cost, and time for selecting soil subgrade soil for roads, the CBR value can be developed using regression techniques by performing numerous CBR and physical tests considering different soil types. The main objective of this study was to examine the correlation of CBR value with soil properties of road subgrade. Twenty-seven specimens were obtained from twenty different provinces in Cambodia. The basic properties tests (Sieve analysis, Atterberg limit, compaction test, and CBR test) were conducted. From the test result, multiple linear regression was adopted to correlate the prediction model of the CBR. Based on the current study, it was found that the prediction model with the function of gravel, sand, fine, plastic index, maximum dry density, and optimum water content provided a better coefficient of determination (R2) for both study and validating data, which was about 0.9215 and 0.8348, respectively. However, another model is preferable practically since it relates only to the sieve analysis parameter. That model also has better R2 for training (R2 = 0.8901) and validating data (R2 = 0.6969). Therefore, that model should commonly be used for the primary check of the soil in the field due to human effect, costly and time-consuming.*

Keywords: California Bearing Ratio, Soil index tests, Correlation equation, Linear regression models

1. INTRODUCTION

In a general view of the bearing capacity of road subgrade, the California Bearing Ratio (CBR) is characterized as a primary index for design and construction. The California bearing ratio (CBR) value is one of the parameters commonly used to measure the strength of the subgrade, as described by Anagnostopoulos and Chatziangelou (2008) [1].

As road components are either flexible or rigid pavement structures, the subgrade is constructed as the primary foundation supporting part of the road and fully complying with all requirements of transport livelihood in all environmental conditions.

The bearing capacity of road subgrade is influenced by several factors, including the soil's grain size distribution, plasticity, compaction, and moisture content. In practice, soils with a high percentage of fines, high plasticity, and high compaction have a higher CBR.

The prediction of CBR with soil properties of road subgrade material is an active research topic. Many previous studies have been conducted to estimate CBR from liquid limit (LL), plasticity index (PI), plastic limit (PL), maximum dry density (MDD), optimum moisture content (OMC), percentage of sand (S), gravel (G), and fines (F). Some references to previous studies are shown in Table 1.

Especially in Cambodia, this kind of study research, especially the inter-relationship of all parameters of physical and mechanical properties of the material used in the subgrade, is rarely noted in the literature. To extend the experimental work from abroad studies into Cambodia's condition, this paper objectively develops a new prediction model for the CBR value of soil subgrade using a linear regression model. The model will

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minimize the human effect, cost, and time required to select subgrade soil in Cambodia. The prediction model can be developed using regression techniques by performing numerous CBR tests on several soil types. Twenty-seven soil samples were obtained from twenty different provinces in Cambodia for this study.

Table 1 Summary of previous multiple regression analysis

No.	Authors	Model	Soil Type
1	Katte et al., 2019 [2]	CBR=-20.19+47.130MDD-2.895OMC-0.091PL-0.055PI+0.049G-0.668S+0.000F	Clayey soil
2	PhyuPhyu and NyanMyint, 2017 [3]	CBR=0.31314PI+25.71882MDD	Highly organic soil
3	Iqbal et al., 2018 [4]	CBRS= 11.2525LL-26.4144PI-0.3024F+153.7175	Silty soil, clayey soil
4	Rakaraddi and Gomarsi, 2015 [5]	CBR= -0.275LL+0.118PL+0.033F+5.106G	Clayey soil
5	Ramasubbarao and Sankar, 2013 [6]	CBR= 0.064F + 0.082S + 0.033G – 0.069LL + 0.157PL – 1.810MDD – 0.061OMC	Clayey sand, Fat clayey soil, Silty clay, Well graded sand
6	Shirur,and Hiremath, 2014 [7]	CBR= -4.8353-1.56856OMC+4.6351MDD	Fat clayey soil, Silty clay
7	Khatri et al., 2019 [8]	CBR= -0.057LL+0.23PI+0.23F-3.26OMC-73.92MDD-0.04S+232.66	All types of soil
8	Lakshmi et al., 2016 [9]	CBR = $-15.692MDD^2+66.821MDD-68.29$	Silty clay, Clayey Soil
9	Janjua and Chand, 2016 [10]	CBR= 0.142F+0.0262LL+0.0283OMC+1.043MDD-17.029	Well-graded sand containing silt

Table 2 Preliminary study between previous models and current field data in Cambodia

No.	Previous study	R^2 value
1	Katte et al., 2019 [2]	0.0114
2	PhyuPhyu and NyanMyint, 2017 [3]	0.1013
3	Iqbal et al., 2018 [4]	0.1460
4	Rakaraddi and Gomarsi, 2015 [5]	0.1061
5	Ramasubbarao and Sankar, 2013 [6]	0.0043
6	Shirur and Hiremath, 2014 [7]	0.1147
7	Khatri et al., 2019 [8]	0.2741
8	Lakshmi et al., 2016 [9]	0.3540
9	Janjua and Chand, 2016 [10]	0.5945

2. MATERIALS AND METHODS

2.1. Materials

The location where extracted those samples is shown in Fig.1. The material (Fig.2) used in this study is about 27 soil samples collected from twenty different provinces (Bunteay Meanchey, Battambang, Pailin, Pursat, Koh Kong, Kampong Chnang, Kondal, Kampong Speu, Takeo, Kampot, Kep, Prey Veng, Svay Rieng, Tbong Khmum, Kampong Cham, Kratie, Mondulkiri, Stung Treng, Ratanakiri and Preah Vihear). The pavement materials such as gravel, sand, and clay/silt were performed for the basic properties tested at the Ministry of Public Works and Transport (MPWT) laboratory. The experiments followed the ASTM standards. The basic properties of all samples are summarized in Table 3.

2.2 Multi linear regression

The linear regression model (LR) is a mathematical technique for predicting the relationship between a dependent and one or more independent variables [1]. In general, the equation of the Multiple Linear Regression (MLR) model can be expressed by Eq. 1.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_n x_n + intercept$$
(Eq. 1)

Where $\beta_0, \beta_1, \beta_2, \ldots, \beta_n$ and intercept are constant, $x_i \geq 0$ is soil properties parameters (independent variables), y is CBR value (dependent variable).

As aforementioned, the laboratory tests (Fig. 3), such as sieve analysis [11], Atterberg limit tests [12], compaction tests [13], and California Bearing Ratio tests [14], were conducted to obtain all six soil properties including percentage of gravel, sand, fine, liquid limit (LL), Plastic limit (PL), Maximum dry density (MDD), and Optimum moisture content (OMC) to develop the prediction model of the CBR value by using Multiple Linear Regression (MLR).

2.3. Evaluation criteria

In the present study, the coefficient of determination (R^2), Mean Average Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Percentage of Error (%Error) were adopted to evaluate the performance of the prediction model. The formulas are provided in Eqs. 2 to 6, respectively.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2} \quad \text{(Eq. 2)}$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|y_i^{real} - y_i^{pred}\right| \quad \text{(Eq. 3)}$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(y_i^{real} - y_i^{pred}\right)^2 \quad \text{(Eq. 4)}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(y_i^{real} - y_i^{pred}\right)^2} \quad \text{(Eq. 5)}$$

$$\%Error = \frac{\left|y_i^{pred} - y_i^{real}\right|}{y_i^{real}} \times 100 \quad \text{(Eq. 6)}$$

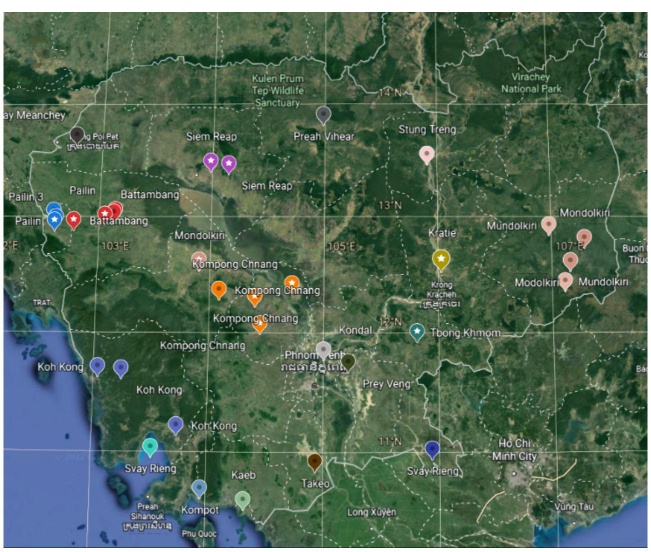

Fig. 1. Location of the collected soil sample.

Where: n = Number of data point y_i is actual CBR value $\hat{y}_i$ is Predicted CBR value, $\bar{y}_i$ is the average measured value, y_i^{real} is the actual data, and y_i^{pred} is the predicted data.

The coefficient of determination (R^2) is predictable from the independent variables. It is theoretically represented as a value ranging from 0 to 1. A value of 0 indicates that the determination fails to accurately model, while a value of 1 shows a perfect fit and is thus highly reliable and accurate [15].

The results of the laboratory tests of CBR with different soil properties are presented in Table 4. Those soil parameters were used as the regression variables to apply the MRL method and to estimate the correlation equation with the CBR values. Moreover, the developed prediction model will be practical within the range of 0% ≤ Gravel ≤ 56%, 0% ≤ Sand ≤ 58%, 0% ≤ Fine ≤ 100%, 1% ≤ PI ≤ 40%, 1% ≤ OMC ≤ 25%, and 0 g/cm^3 ≤ MDD ≤ 3 g/cm^3.

Fig. 2. Soil samples collected from provinces in Cambodia.

3. RESULTS AND DISCUSSIONS

3.1. The effect of soil properties on Soaked CBR

The effect of soil properties on CBR value can be explained as optimum water content (OMC) and plasticity index (PI) are influenced by CBR value. However, CBR value varies with those two parameters such as PI or OMC increase, CBR value decreases. This due to the high amount of water contained in the soil (over optimum range) resulted in soil with has high plasticity index. It often loses its stiffness and strength and induces plastic deformation, which has the potential to cause low CBR values. The consistent behaviors of various soil properties with soaked CBR are shown in Fig. 5.

Table 3 The summary results of soaked CBR (Training data) from the laboratory of MPW

N (%)	Soil Type	Sieve Analysis in %			Atterberg Limit %		Compaction characteristic		CBR
		F (%)	S (%)	G (%)	LL	PI	MDD (g/cm3)	OMC (%)	Soaked (%)
1	A-6	81.4	11	7.6	39.1	22.66	1.634	17.1	2.8
2	A-6	73	17	10	38.9	19.27	1.65	17	3.1
3	A-4	44.57	22.55	32.88	22.69	5.43	2.055	5.71	12.59
4	A-6	77.18	19.61	3.21	30.88	11.2	1.864	3.05	7.11
5	A-6	81.78	17.58	0.64	33.3	13.17	1.898	2.6	6.8
6	A-6	90.3	9.38	0.32	45.7	24.14	1.878	7.78	4.23
7	A-6	86.02	9.66	4.32	33.19	16.67	2	6.48	3.43
8	A-4	65.43	17.34	17.23	28.36	9.83	1.794	10.22	9.38
9	A-6	88.61	9.85	1.54	43.44	24.29	1.759	5.31	4.48
10	A-7-6	36.17	26.48	37.35	47.41	17.89	1.768	10.06	10.04
11	A-6	86.23	7.72	6.05	33.53	15.65	1.866	4.77	6.54
12	A-6	82.34	8.12	9.54	39.19	20.38	1.892	5.75	2.95
13	A-7-6	58.84	13.22	27.94	49.25	21.97	1.724	5.57	9.89
14	A-7-6	81.27	8.4	10.33	53.39	27.8	1.811	4.08	4.97
15	A-7-6	98.13	1.52	0.35	44.22	29.19	1.772	9.57	2.83
16	A-6	81.03	18.69	0.28	32.73	14.44	1.877	3.19	4.65
17	A-6	20	28	52	28.4	13.39	1.936	10.2	16.5
18	A-2-6	90.2	9.3	0.5	45.09	24.87	1.784	15.4	3.5
19	A-2-6	21.38	23.46	55.16	25.09	11.16	2.092	1.58	17.81
20	A-6	70.1	17.1	12.8	36.4	17.09	1.812	12.3	2.9
21	A-7-6	96.53	1.72	1.75	45.2	29.55	1.744	9.11	2.47
22	A-6	96.65	2.08	1.27	41.77	22.64	1.827	7.59	3.48
23	A-6	68.22	12.72	19.06	37.31	18.53	1.978	5.89	5.75
24	A-7-6	99.24	0.7	0.06	51.12	27.97	1.758	9.59	1.39
25	A-7-6	98.61	1.33	0.06	49.95	29.81	1.75	11.83	1.46
26	A-6	88.93	9.76	1.31	34.25	13.19	1.819	4.55	2.24
27	A-6	99.27	0.73	21.3	51.12	39.12	1.585	21.09	0.95

Table 4 The statistical analysis results of soaked CBR

Statistics	% Gravel	% Sand	% Fine	%LL	%PI	MDD (g/cm^3)	% OMC	CBR
No. Sample	27	27	27	27	27	27	27	27
Minimum	0.06	0.7	20	22.69	5.43	1.585	1.58	0.95
Maximum	55.16	28	99.27	22.69	39.12	2.092	21.09	17.81
Median	6.05	9.85	81.78	35.7	18.53	1.812	5.75	4.48
Mean	12.40	12.04	12.40	37.44	18.94	1.83	7.83	5.79
Variance	252.27	64.72	508.69	7704	50.81	0.01	27.17	19.35
Standard Deviation	15.88	8.04	22.55	8.78	7.13	0.12	5.21	4.40

Fig. 3. All conducted laboratory tests.

3. RESULTS AND DISCUSSIONS

3.1. The effect of soil properties on Soaked CBR

The effect of soil properties on CBR value can be explained as optimum water content (OMC) and plasticity index (PI) are influenced by CBR value. However, CBR value varies with those two parameters such as PI or OMC increase, CBR value decreases. This due to the high amount of water contained in the soil (over optimum range) resulted in soil with has high plasticity index. It often loses its stiffness and strength and induces plastic deformation, which has the potential to cause low CBR values.

The consistent behaviors of various soil properties with soaked CBR are shown in Fig. 5. Referring to Fig. 5a and 5b, the coefficient of determination R^2 was found to be 0.4077 for CBR vs. PI and 0.1481 for CBR vs. OMC. The effect of soil properties on CBR value can be explained as if optimum moisture content (OMC) and plasticity index (PI) increase, CBR value decrease.

Fig. 5c represents the results of CBR in terms of various maximum dry density (MDD). The overall trend shows that the CBR value increased with MDD. This is due to the rearrangement of soil particles after compaction changing the soil structure from a loose to a dense state.

Fig. 5d and 5f show the results of soaked CBR with G and S. The coefficient of determination R^2 was found to be 0.7334 for CBR vs Gravel and 0.6189 for CBR vs Sand. The effect of soil properties on CBR value can be explained as if the fraction of Gravel and Sand increase, CBR value increase. This is because gravel and sand could improve both geotechnical and strength properties [16].

Fig. 5e shows the results of soaked CBR with Fine (F). The coefficient of determination R^2 was 0.8519 for CBR vs Fine. The effect of soil properties on CBR value can be explained as if the fraction of Fine increases, CBR value decreases. The high fine fraction seriously affected the soil-bearing capacity (CBR). This is because the percentage of fines increased the plasticity index of the soil, which decreased the permeability of the soil and its ability to support load by Azad (2010).

3.2. The development of the prediction model by LR

A total of 27 datasets (Training data) were used to develop the prediction equation of the CBR value based on linear regression analysis. The different lines of regression by each model (referring to the developed model in Table 5) were plotted in Fig. 4. The R-square values are referred to the coefficient of determination between predicted CBR (results from the prediction model) and actual CBR (from laboratory tests)

It can be seen that the three suggested prediction models, 1, 3, and 4, show a good correlation that the R^2 is about 0.8901, 0.9048, and 0.9215, respectively.

Models 1, 3, and 4 have better R-square, MAE, MSE, and RMSE than model 2. This means that models 1, 3, and 4 have a low error when predicting values. However, all four prediction models will be chosen for validation with the CBR values of other studied soil types selected from datasets as in Table 6.

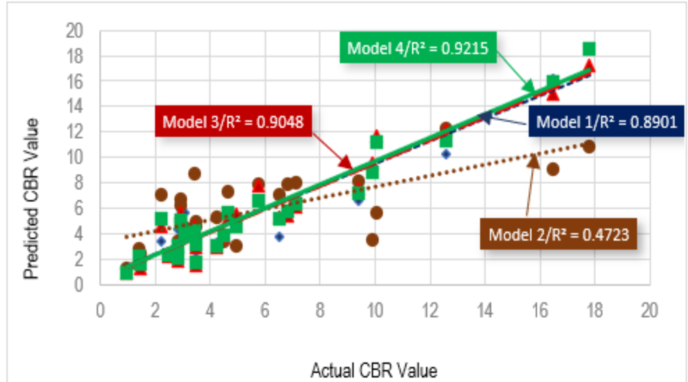

Fig. 4. Comparison between predicted CBR and actual CBR.

Table 5 Summary of prediction model by multi-linear regression (MLR) for CBR

Model	Description	Regression equation	R^2	MAE	MSE	RMSE
Model 1	CBR versus F, S, G	CBR= -0.24323F+0.58833S+0.48935G-0.0078978F*S-0.005334F*G-0.025746S*G+26.494	0.8901	1.1652	3.1282	1.7687
Model 2	CBR versus PI, OMC, MDD	CBR= -0.26116I+13.347MDD+0.10142OMC-14.289	0.4602	2.3858	11.8560	3.4433
Model 3	CBR versus G, S, F, PI, OMC, MDD	CBR = -0.1013F-0.39008S+0.10462G-0.0704IP-0.25038MDD-0.19975OMC+16.17	0.9048	1.0913	2.4043	1.5506
Model 4	CBR versus G, S, F, PI, OMC, MDD	CBR= -0.027982F+0.1787S+0.38056G-0.12126IP-2.6856MDD-0.18051OMC-0.0019486F*S-0.0029757F*G-0.0070987S*G+14.842	0.9215	0.9959	2.3399	1.5277

Fig. 6 shows the accuracy and reliability of the prediction model, which was evaluated by comparing the value of the predicted CBR from the current study with the CBR from previous studies [8-9, 17].

In the developed model 1, the CBR was functioning with the physical properties G, S, and F. By using this Model: CBR= -0.24323F+0.58833S+0.48935G-0.0078978F*S-0.005334F*G-0.025746S*G+26.494 after validation with previous study data, the coefficient of determination R^2= 0.6969. In the developed model 2, the CBR was functioning with the physical properties PI, MDD, and OMC, by using this Model: CBR= -0.26116PI+13.347MDD+0.10142OMC-14.289 after validation with previous study data, the coefficient of determination R^2= 0.2977.

In the developed model 3, the CBR functions with physical and mechanical properties following the combination of G, S, F, PI, MDD, and OMC. By using this Model: CBR = -0.1013F-0.39008S+0.10462G-0.0704IP-0.25038MDD-0.19975OMC +16.17 after validation with previous study data, the coefficient of determination R^2= 0.8275.

In the developed model 4, the CBR was functioning with both physical and mechanical G, S, F, PI, MDD, and OMC, but add the interactive parameters FS, FG, and SG By using this model: CBR= -0.027982F+0.1787S+0.38056G-0.12126IP-2.6856MDD-0.18051OMC-0.0019486F*S-0.0029757F*G-

0.0070987S*G+14.842 show after validation in equation above with previous study data, the coefficient of determination R^2= 0.8348.

Among the four models, and even if the determination of coefficient R^2 of some models can be adopted for acceptable practice, it is necessary to analyze the frequency data (numbers of samples) that lower than 20% of errors between the previous and current studies, as shown in Fig. 7.

Generated from Fig. 7 of models 1, 2, 3, and 4, it shows that data under the dashed line around 33%, 18%, 36%, and 61% of the total number of samples of the predicted CBR had errors less than 20% compared to the CBR from previous studies. It can be concluded that the prediction equation in Model 4 can be applied to predict the CBR value of subgrade soil.

Therefore model 1 was developed and included only three simple parameters of soil properties (percentage of Gravel, Sand, and Fine), which were facilitated to determine by conducting field or lab test-only sieve analysis. However, the R^2 value was less than in models 3 and 4.

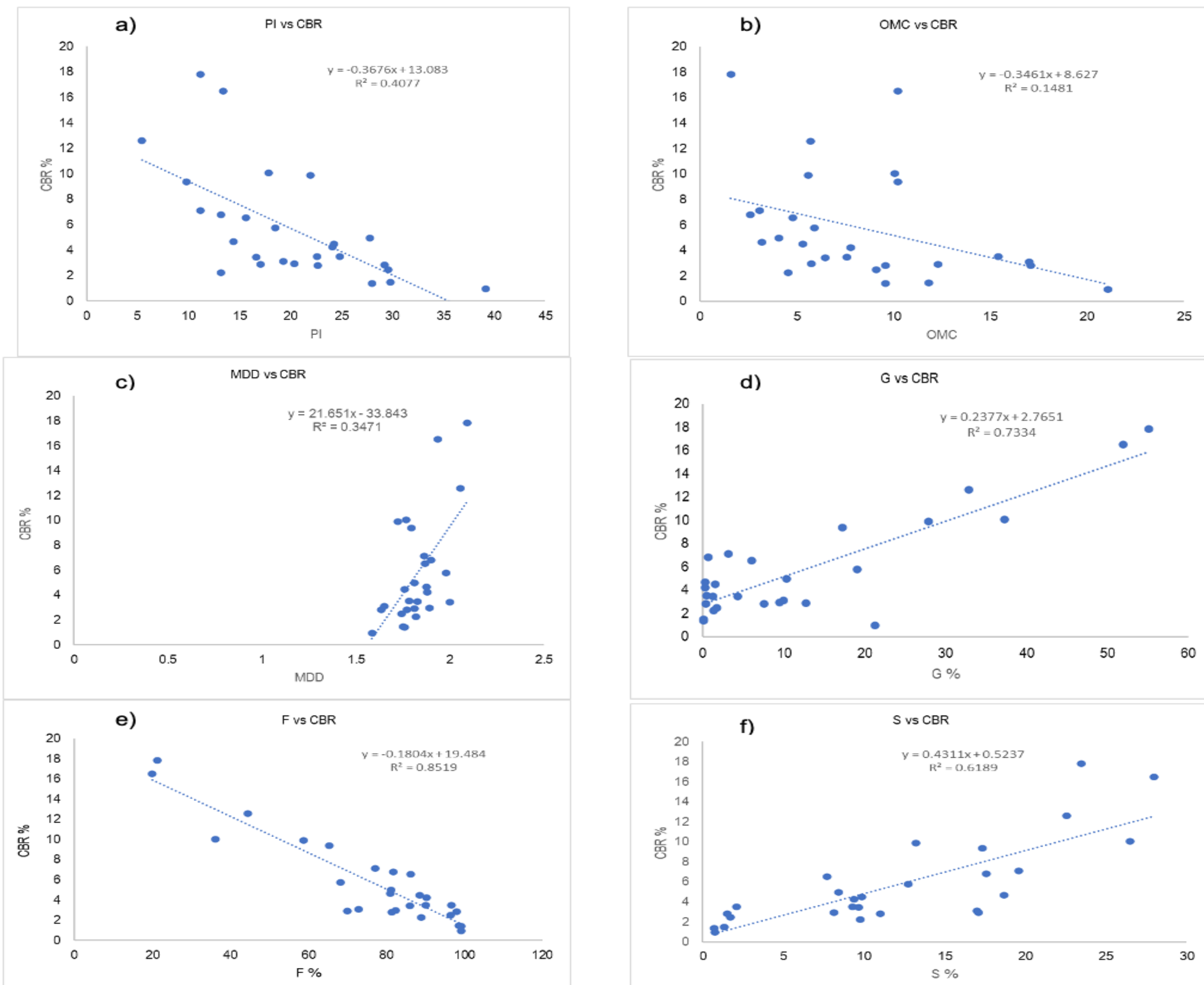

Fig. 5. The consistency results of CBR with soil properties: a) PI, b) OMC, c) MDD, d) Gravel, e) Fine, f) Sand.

Table 6 The CBR datasets (Validating data) from previous studies for validation

Nº	Reference	Sieve Analysis in %			PI (%)	Compaction Characteristic		CBR
		F	S	G		MDD	OMC	Soaked
1	[8]	5.54	42.01	52.45	5.07	2.15	9.97	14.8
2		6.56	40.85	52.6	6.43	2.17	9.82	10.1
3		7.58	39.69	52.74	7.79	2.18	9.67	16.8
4		6.83	39.69	53.48	7.67	2.17	9.51	10.1
5		6.08	40	54.22	7.55	2.15	9.35	15.8
6		4.98	39.58	55.44	9.89	2.19	9.04	15.9
7		6.34	37.56	56.11	9.63	2.15	9.35	12
8		9.79	43.2	47.01	8.74	2.16	9.9	14.17
9		6.14	33.9	59.97	8.47	1.92	14.09	18.78
10		10.44	51.08	38.48	7.95	1.9	12.8	17.78
11	[2]	99.2	0.8	0	41	1.66	22.4	1.71
12		97.9	2.1	0	25.9	1.64	23.1	2.35
13		96.4	3.6	0	20.1	1.67	19.9	2.42
14		93.5	6.5	0	34.4	1.65	20.6	2.11
15		98.5	1.5	0	35.2	1.63	24.4	2.01
16		64.8	35.2	0	7.6	1.73	20.1	2.95
17		71.1	28.9	0	6.2	1.72	20.6	3.06
18		30	13.7	55	38.9	2.002	12.3	18.5
19	[17]	68.71	28.94	2.35	7.97	1.7	15.11	5.62
20		68.71	28.94	1.31	7.52	1.71	15.2	5.77
21		69.22	30.14	0.64	7.69	1.69	15.35	5.69
22		58.77	36.52	4.71	6.95	1.72	15.62	5.81
23		62.38	35.23	2.39	6.12	1.77	14.39	6.12
24		63.55	35.01	1.44	6.56	1.76	14.92	6.1
25		70.21	29.44	0.35	8.46	1.64	15.82	5.72
26		68.71	28.94	2.35	6.52	1.75	14.42	6.2
27		71.21	26.92	1.87	6.72	1.74	14.16	6.05
28		74.06	25.94	0	7.15	1.73	15.62	5.95
29		79.23	18.12	2.65	8.11	1.62	15.76	5.67
30		71.11	27.64	1.25	7.35	1.66	15.52	5.92
31		69.27	26.92	3.81	7.25	1.68	15.62	5.88
32		83.21	13.44	3.35	8.12	1.71	15.4	5.98
33		69.41	28.21	2.38	7.02	1.74	14.65	6.02

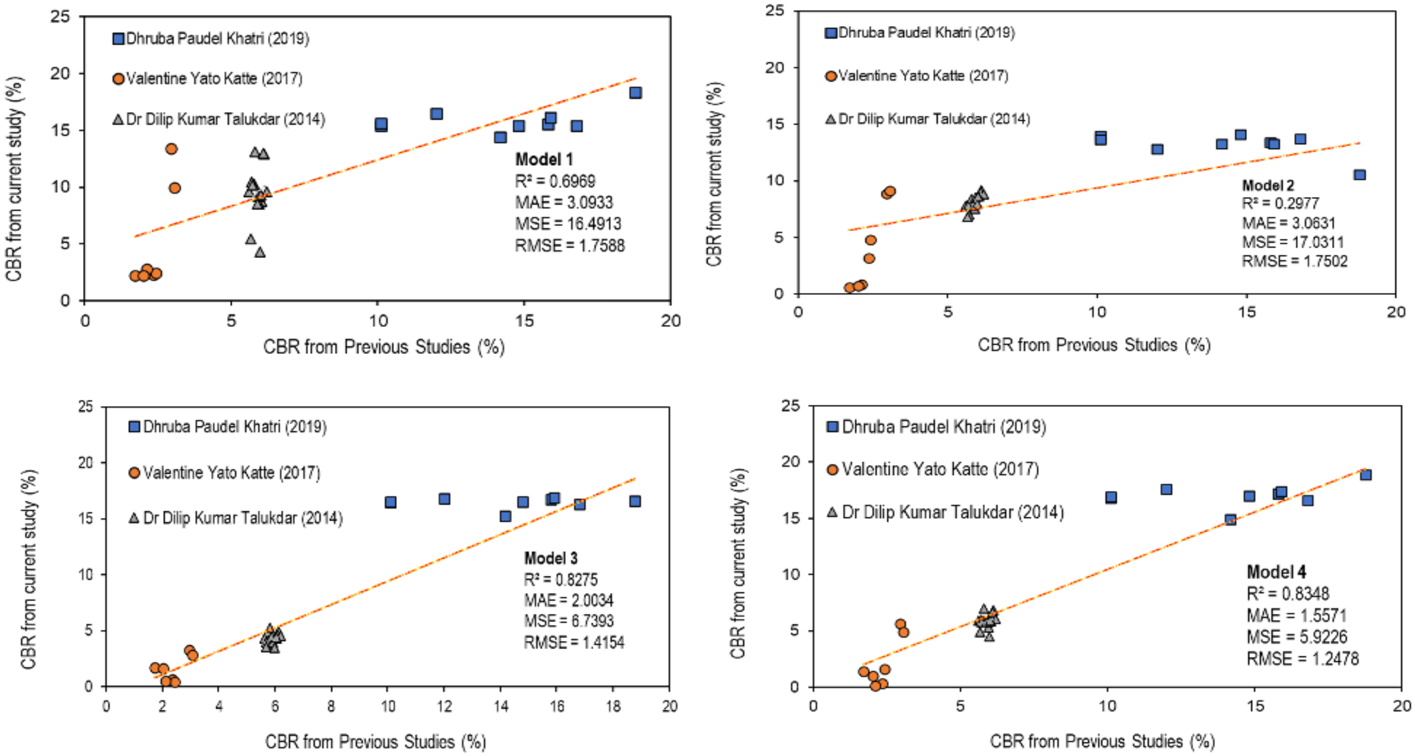

Fig. 6. The comparison between predicted CBR in the current study and CBR from the previous study.

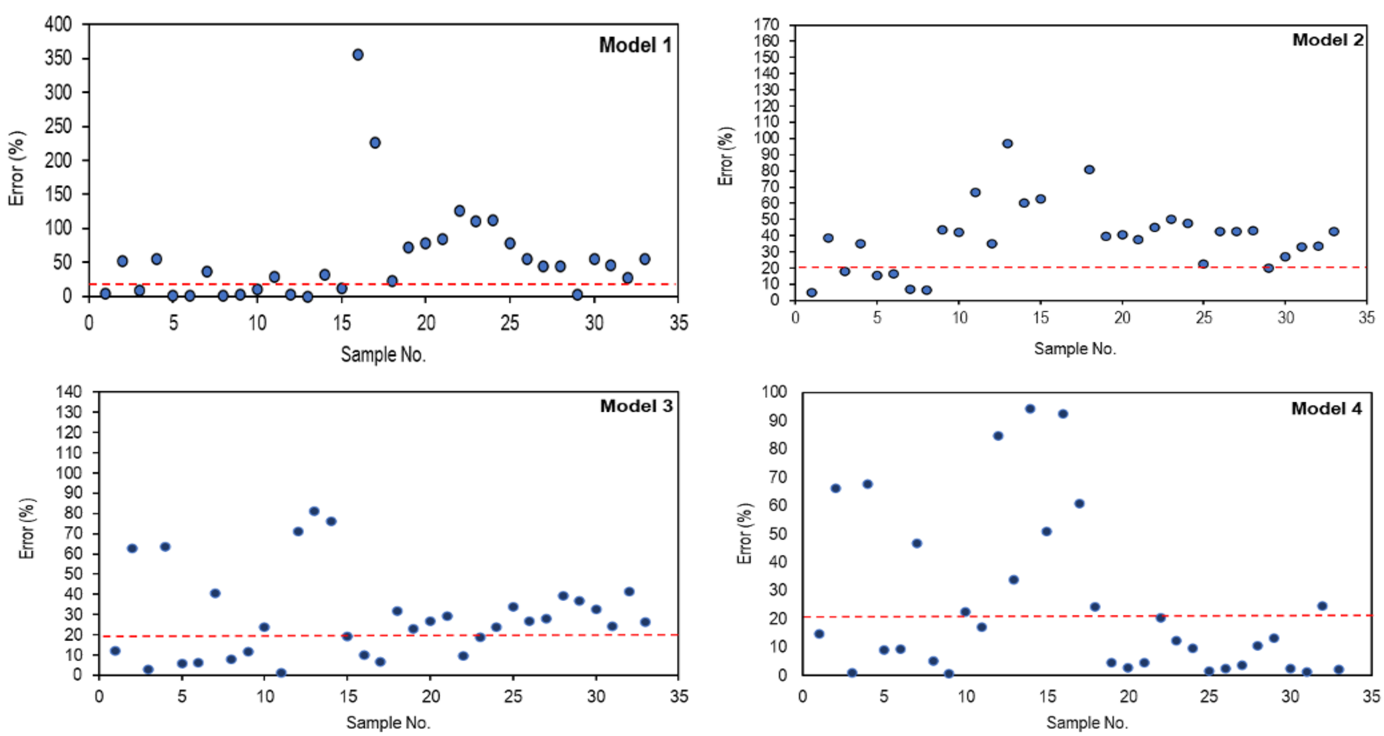

Fig. 7. Variation in the error and number of soil samples.

4. CONCLUSIONS

The output study of the correlations between CBR value based on the physical and mechanical properties of soil in Cambodia can conclude as follow:

- Based on the value of the coefficient of determination (R-square) of the above-developed MLR models for soaked CBR generated from the field data test in Cambodia and validated with the data from different resources, it has been noted that models 4 provide a better correlation with both physical and mechanical properties using for soil subgrade material.
- For practically used, with less time-consuming and more economical, model 1 is preferable since it is related only to the sieve analysis parameters (percentage of Gravel, Sand, and Fine). It is convenient for field engineers to probe the soil for construction. Therefore, fully determine the whole parameters requested by the construction specification.
- As Model 1 is used to assist in fieldwork selection on material, the recommendation of Model 4 is used for the full requirement determined by technical or specific laboratory.

CBR predicted equation in the proposed model (models 1 and 4) would be more feasible in the construction field, such as the pathway of selecting material from borrow pit (economizing time). It also assists the road engineer in the preliminary evaluation of material properties of subgrade in accordance with standard requirements imposed by the employer.

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