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Research Article

Correlation of Unconfined Compressive Strength (UCS) with Compaction Characteristics of Soils in Burayu Town

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The unconfined compressive strength is the most widely used parameter to measure the strength of the subgrade or foundation soil for cohesive soils. Due to its time-consuming and cost-effective nature, most of the time-correlation equations have been used to correlate unconfined compressive strength with compaction parameters and soil index properties. The current study was conducted in Burayu town where fifty soil samples were collected and experimental geotechnical soil tests were carried out based on the American Society for Testing and Materials (ASTM) standards. The correlation and regression analyses were done using the experimental results obtained for unconfined compressive strength (UCS) and compaction characteristics. The regression analysis resulted in a fair coefficient of correlation of 0.61 and 0.78 for single linear regression of UCS with maximum dry density (MDD) and optimum moisture content (OMC), respectively, while $R^2 = 0.83$ for multiple linear regression analysis of UCS with MDD and OMC. After further emphasis, the equation developed using multiple linear regression ($\text{UCS} = -3105 + 1625\ \text{MDD} + 40.9\ \text{OMC}$, $R^2 = 0.83$) which was chosen as a prediction equation. After validation of the established model using control tests, the statistical regression analysis shows that the correlation is 97% accurate in the UCS determination for multiple regression analysis. This implies that the established model could be used to predict the UCS in the study area.

1. Introduction

A characteristic of real clay is the property of cohesion, sometimes referred to as no-load shear strength. Unconfined specimens of clay soil derive strength and firmness from cohesion. The shear strength of saturated cohesive soil in an undrained shear test (i.e., a trial in which volume change is prevented) is derived entirely from cohesion. It is known that the shear strength of cohesive clay varies with its consistency. The same clay, which is at the liquid limit, has very little shear strength, whereas the same clay at lower moisture content may have considerable shear strength [1, 2]. Shear strength may be defined as the resistance to shearing stresses and a consequent tendency for shear deformation. The shear strength of soils is an essential parameter for many foundation engineering problems, such as the bearing capacity of shallow foundations and piles, lateral Earth pressure on retaining walls, and the stability of the slopes of dams and embankments [3]. A soil derives its shearing strength from resistance due to the interlocking of particles, the frictional resistance between the individual soil grains due to sliding or rolling friction, and cohesion between soil particles. Granular soils of sands may derive their strength from the first two sources, while cohesive soils may derive their shear strength from the second and third sources. However, highly plastic clays may exhibit the third source alone for their shearing strength [4].

Determining the engineering properties of soils plays a significant role in solving different geotechnical engineering problems. Shear strength tests are one of the major tests used to determine the shear strength parameters of the soil. The shear strength of the soil is stated by cohesion (c) and the friction angle (φ). The two parameters mentioned primarily define the soil's maximum ability to resist shear stress under a defined load [5]. The soil strength parameters, such as cohesion and the angle of internal friction of soil, are necessary for estimating the soil's load-bearing capacity, the stability of geotechnical structures, and analyzing stress and strain characteristics of soils [6]. Determining the undrained shear strength is used to determine the bearing capacity and geotechnical structure's stability in proper short-term loading conditions. The undrained shear strength of soils may depend on natural water content, the type of soil considered, and the soil [1].

In civil engineering practice, the prediction of remolded shear strength of fine-grained soils is essential for geotechnical design. Engineers estimate soil strength using simple index properties such as the plastic limit, liquid limit, clay mineralogy, particle gradation, and water content. Soils with different liquid limits or plastic limits cannot be expected to have a unique undrained shear strength value [7, 8]. The prediction of undrained shear strength of the soil depends only on the liquidity index. The estimation is reasonable when the undrained shear strength is in the remolded state. As a consequence, such a prediction will be conservative and lead to actual lower in situ strength. The correlation is very important where good quality samples and tests are challenging and expensive to obtain [9]. Mohammed [10] conducted the correlation between the liquid limit, dry density, plastic index, and moisture content. The models were analyzed using nonlinear multiple regressions. The hyperbolic model was useful in estimating the undrained shear strength of clay soils based on the coefficient of determination (R^2) and root mean square error. Matsumura and Tatsuoka [11] described how shear strength properties are significantly influenced by the degree of soil saturation and dry density.

In the preliminary stages of geotechnical design, empirical correlations are valuable when there are limited soil exploration funds. The shear strength and consolidation of clay can be estimated from simple index properties with little or no cost [12]. Conducting laboratory tests to characterize soil properties is time-consuming, requires enormous effort, and is usually expensive. Therefore, estimating soil behavior using analytical models is useful in project feasibility studies, early decisions in the field, and parametric evaluations [13], but this is due to handling, transportation, the release of overburden pressure, and poor laboratory conditions. It is difficult to obtain accurate undisturbed samples for shear strength tests [14]. The ever-increasing cost of shear-strength laboratory equipment and tests also raises construction projects' prices [15]. Due to the nature and variety of geological processes that occurred in the soil formation, soil properties change from region to region and season to season. Studying this variation in different soil types and origins is a critical task for geotechnical engineers. To overcome this variation's effects, geotechnical engineers and other professionals attempt to develop empirical equations specific to a particular region and soil type to use them for a different purpose. However, these empirical equations are more reliable for the soil where the correlation is developed [16].

This study aims to correlate the compaction characteristics and unconfined compressive strength of the soil. Laboratory compaction tests are a common and comprehensive practice for geotechnical projects. So, the prediction of some properties such as unconfined compressive strength parameters for soil with compaction characteristics provides an excellent alternative to obtain undrained shear strength parameters without conducting undisturbed samples. Drusa et al. [17] suggested that the most important factors for the design of a safe foundation structure are the determination of geotechnical parameters and the selection of the appropriate calculation method. Therefore, a correlation between these soil parameters would be highly appreciated.

2. Materials and Methods

2.1. Study Area. The study was conducted in the western Oromia Burayu town of Ethiopia. Burayu town is located in the Oromia National Regional State to the west of Addis Ababa, along the Addis Ababa-Ambo road, 15 km away from Addis Ababa's center. Astronomically, the town extends roughly from 9°02′ to 9°02′30″ North latitudes and 38°03′30″ to 38°41′30″ East longitudes [18]. The map of the study area is shown in Figure 1.

Different locations in Burayu town were selected to get reliable and sufficient data required for the analysis by conducting various geotechnical laboratory tests. Thirty disturbed and undisturbed samples were taken from different localities of the town within a reasonable interval of sampling. In addition to this, twenty test results obtained from secondary data were added. The coordinates of the sampling points and locations are shown in Table 1.

2.2. Sample Collection. The reconnaissance survey and desk work of the town are done by taking permission from the respective town administration. Sampling locations are selected to represent the town. Sampling was carried out using a boring hole at each selected sampling point. The collected samples from trial pits were placed in sealed plastic bags and carefully transported to the laboratory for different geotechnical soil tests. In the laboratory, the collected samples are allowed to air-dry where their sizes are reduced into smaller fragments without altering individual particle sizes [20, 21].

2.3. Geotechnical Tests. Different geotechnical soil tests were carried out to determine the engineering properties of the studied soils. These tests were grain size analysis, compaction test, the Atterberg limit (liquid limit and plastic limit), and UCS. These geotechnical tests were conducted according to the test specification shown in Table 2.

3. Results and Discussion

3.1. Geotechnical Characterization of the Studied Soils. The engineering properties of the sampled soils are determined according to standard specifications specified in Table 2. The entire laboratory tests were performed in the

Figure 1: The study area Map [19].

Table 1: Sample designation and global coordinates of sample locations.

Sample designation	Location	Northing	Easting	Elevation (m)
TP-1	Leku Keta 1	9.05716	38.6816	2512
TP-2	Burayu Keta	9.07458	38.676	2585
TP-3	Leku Keta 2	9.07283	38.6849	2586
TP-4	Gefersa Burayu	9.07001	38.6632	2616
TP-5	Gefersa Nono 2	9.06383	38.6116	2619
TP-6	Gefersa Guji 2	9.08048	38.6275	2640
TP-7	Gefersa Nono 1	9.07306	38.6196	2615
TP-8	Melka Gefersa 2	9.05467	38.6372	2605
TP-9	Gefersa Guji 1	9.07831	38.6382	2610
TP-10	Melka Gefersa 1	9.05647	38.6512	2600

Jimma Institute of Technology Geotechnical Engineering Laboratory using the following standard testing procedures in Table 2. The geotechnical test results indicate that all of the soils in the study area are classified under CH, which means that the soils are highly plastic clays as shown in Table 3 [22, 24]. Table 3 shows the experimental test results of the liquid limit (LL), plastic limit (PL), plastic index (PI), specific gravity (Gs), and natural moisture content (NMC) at each test point represented as TP.

Table 2: Summary of laboratory testing procedure standards.

Test description	Standard testing procedure
Grain size distribution analysis	ASTM D 422–98
Natural moisture content	ASTM D 2216–98a
Atterberg limits	ASTM D 4318–98
Specific gravity	ASTM D 854–98
Compaction test	ASTM D 698
Unconfined compressive strength	ASTM D 2166–98a

A total of fifty test pits were used to obtain the geotechnical properties of the soils in Burayu town. Among these fifty samples, thirty test results were obtained from experimental tests in the laboratory, and additional twenty test results were obtained from previously done projects in the town which were used as secondary data in this study as shown in Table 4.

3.2. Statistical Analysis

3.2.1. Descriptive Statistical Analysis. The laboratory test results obtained were analyzed using SPSS (statistical package for social science software) to evaluate the significance of each variable. Details of descriptive statistics (mean, median, variance, standard deviation, and range) were performed as shown in Table 5. Table 5 shows the descriptive analysis results of the samples, while Table 6 indicates the Pearson correlation analysis of the independent ad dependent variables of the study.

As shown in Table 6, the correlation of unconfined compressive strength with compaction parameters, i.e.,

Table 3: Summary of the laboratory test results.

Sample name	UCS (kPa)	Gs	NMC (%)	OMC (%)	MDD (g/cc^3)	LL (%)	PL (%)	PI (%)	USCS
TP-11	215	2.72	33.29	29.77	1.31	64.99	30.98	34	CH
TP-12	240	2.73	34.33	29.41	1.32	67.44	30.11	37.32	CH
TP-13	253	2.74	34.39	29.54	1.3	61.94	30.59	31.34	CH
TP-21	314	2.74	32.68	30.44	1.32	59.65	30.87	28.78	CH
TP-22	340	2.74	32.7	30.24	1.32	63.78	30.7	33.09	CH
TP-23	366	2.74	33.04	30.36	1.32	67.32	30.43	36.89	CH
TP-31	240	2.74	32.32	30.4	1.31	61.66	30.54	31.12	CH
TP-32	270	2.75	32.43	30.4	1.32	62.33	30.33	31.99	CH
TP-33	297	2.75	32.44	30.48	1.33	67.67	28.87	38.79	CH
TP-41	239	2.75	32	30.71	1.31	59.32	30.31	29	CH
TP-42	241	2.75	32.13	31.01	1.32	67.43	31.25	36.18	CH
TP-43	286	2.76	32.29	31.03	1.32	65.6	31.63	33.97	CH
TP-51	336	2.76	31.91	31.23	1.33	61.46	31.13	30.33	CH
TP-52	327	2.76	31.94	32.42	1.3	60.67	30.59	30.09	CH
TP-53	355	2.76	31.99	32.21	1.33	61.52	30.65	30.86	CH
TP-61	335	2.76	31.81	31.31	1.32	65.57	31.2	34.37	CH
TP-62	341	2.77	31.84	32.37	1.34	67.88	31.39	36.49	CH
TP-63	389	2.77	31.84	32.44	1.34	67.32	32.65	34.67	CH
TP-71	344	2.77	31.69	31.86	1.33	61.54	30.99	30.55	CH
TP-72	346	2.78	31.77	30.73	1.34	69.37	32.98	36.39	CH
TP-73	349	2.78	31.8	31.3	1.35	67.24	32.09	35.15	CH
TP-81	505	2.79	31.35	34.16	1.33	67.45	32.15	35.31	CH
TP-82	516	2.79	31.42	33.54	1.35	70.36	33.19	37.18	CH
TP-83	503	2.79	31.5	34.36	1.36	70.04	32.69	37.36	CH
TP-91	432	2.8	31.28	32.54	1.37	68.96	32.68	36.28	CH
TP-92	433	2.8	31.28	32.74	1.33	70.16	32.91	37.25	CH
TP-93	496	2.8	31.33	33.34	1.34	68.41	32.04	36.37	CH
TP-101	429	2.8	30.98	32.7	1.35	70.19	33.12	37.07	CH
TP-102	434	2.8	31.19	33.4	1.36	71.34	33.08	38.26	CH
TP-103	483	2.81	31.2	32.99	1.37	69.47	33.09	36.38	CH

Table 4: Detail descriptions of test results obtained from secondary data.

S. no	UCS (kPa)	MDD (g/cc^3)	OMC (%)
1	219	1.31	29.8
2	243	1.32	29.5
3	257	1.31	29.6
4	317	1.32	30.5
5	344	1.33	31.3
6	370	1.34	32.3
7	242	1.31	31.0
8	271	1.32	30.0
9	300	1.33	30.8
10	240	1.32	29.5
11	243	1.32	30.1
12	288	1.32	30.2
13	340	1.33	31.3
14	330	1.32	32.5
15	359	1.34	32.3
16	340	1.32	31.4
17	335	1.33	32.4
18	383	1.34	32.5
19	408	1.33	31.9
20	342	1.32	30.8

maximum dry density and optimum moisture content, has a significantly strong correlation with coefficients of 0.75 and 0.891, respectively. In addition to compaction parameters, the plastic limit, liquid limit, and specific gravity have relatively good associations with unconfined compressive strength.

3.2.2. Normality Test. The normality test is an essential test to check the data whether the data are normally distributed or not before proceeding with any applicable statistical procedures. The inference or interpretation of the data may not be reliable if the normality of the data is violated. Since the current study considers fifty samples, which is less than 2000, the Shapiro–Wilk test is recommended with valid normality for $p > 0.05$. The Shapiro–Wilk test normality coefficient is determined to be 0.47, which is greater than the 0.05 confidence level showing that the data are normally distributed as shown in Table 7. In addition to this, in Table 7, the skewness and kurtosis coefficients are found to be 0.464 and 0.285 which shows that the data are considered to be normal since the skewness is between −2 to +2 and kurtosis is between −7 to +7.

3.3. Regression. In this study, regression analysis was performed to describe the strength of cohesive soil from compaction characteristics using a statistical approach. To do so, both single linear regression and multiple linear regression models were used. In single linear regression, a single explanatory variable is involved while assessing the relationship between a single response variable and a set of

Table 5: Descriptive Analysis of the studied soils.

	NMC (%)	Gs	UCS (kPa)	MDD (g/cc^3)	OMC (%)
Mean	32.07	2.77	355.13	1.33	31.65
Median	31.88	2.76	342.5	1.33	31.31
Mode	31.84	2.74	240	1.32	30.4
Standard deviation	0.84	0.02	89.78	0.02	1.39
Sample variance	0.7	0	8059.91	0	1.92
Range	3.41	0.09	301	0.07	4.95
Minimum	30.98	2.72	215	1.3	29.41
Maximum	34.39	2.81	516	1.37	34.36
Sum	962.16	83	10654	39.94	949.43
Count	30	30	30	30	30

Table 6: Pearson correlation coefficient table.

	NMC (%)	Gs	UCS (kPa)	MDD (g/cc^3)	OMC (%)
NMC (%)	1	−0.85	−0.713	−0.669	−0.823
Gs	−0.85	1	0.865	0.819	0.862
UCS (kPa)	−0.713	0.865	1	0.75	0.891
MDD (g/cc3)	−0.669	0.819	0.75	1	0.671
OMC (%)	−0.823	0.862	0.891	0.671	1
LL (%)	−0.42	0.652	0.625	0.722	0.519
PL (%)	−0.681	0.834	0.743	0.743	0.71
PI (%)	−0.253	0.478	0.48	0.598	0.363

independent variables. The study considered UCS as the dependent variable, while maximum dry density and optimum moisture content are considered as independent variables. In determining one variable's influence on the other, a stepwise linear regression using both forward selection and backward methods as well as using both MINITAB and SPSS software, the correlation coefficients, and the level of significance has been determined. Pearson's correlation coefficient or the correlation coefficient, R, measures the strength of linear association between two measurement variables. It is calculated as stated by [25].

$$R = \frac{(\operatorname{cov}(x, y))}{(sd(x) * sd(y))}, \tag{1}$$

where

$$\begin{aligned} \operatorname{cov}(x, y) &= \sum_{i=0}^{n} (x_i - \overline{x})(y_i - \overline{y}) \\ &= \text{covariance of } x \text{ and } y \text{ variable}, \\ sd(x) &= \sqrt{\sum_{i=0}^{n} (x_i - \overline{x})} = \text{standard deviation of variable } x, \\ sd(y) &= \sqrt{\sum_{i=0}^{n} (y_i - \overline{y})}, = \text{standard deviation of variable } y. \end{aligned} \tag{2}$$

The value of R ranges from −1 to +1. A value of the correlation coefficient close to +1 indicates a strong positive linear relationship (i.e., one variable increases with the other). A value close to −1 indicates a strong negative linear relationship (i.e., one variable decreases as the other increases). A value close to 0 indicates no linear relationship; however, there could be a nonlinear relationship between the variables [26].

3.3.1. Simple Linear Regression.

3.3.1. Simple Linear Regression. In this study, a single linear regression analysis was conducted using thirty samples to predict unconfined compressive strength. The following models are developed:

Model 1. Prediction of UCS from MDD

The regression analysis shows that the association between UCS and MDD is significantly strong with coefficients of correlation as shown in Figure 2 with equation (1).

$$UCS = -4861 + 3910\ MDD. \tag{3}$$

As shown in Figure 2, the R^2 of regression analysis between UCS and MDD is 0.61. This implies that 61% of the variance in UCS can be accounted for by MDD. The model developed between UCS and MDD is found to be significant with a p value less than 0.05.

Model 2. Prediction of UCS from OMC

The regression analysis shows that the association between UCS and OMC is significantly strong with coefficients of correlation as shown in Figure 3 with the equation established as equation (4).

$$\mathrm{UCS} = -1383 + 54.8\ \mathrm{OMC}. \tag{4}$$

As shown in Figure 3, the R^2 of regression analysis between UCS and OMC is 0.7799. This implies that 77.99% of the variance in UCS can be accounted for by MDD. The model developed between UCS and OMC is found to be significant with a p value less than 0.05.

3.3.2. Multiple Linear Regression Analysis. Multiple linear regression analysis was carried out on fifty samples obtained from primary and secondary data. Before performing the regression analysis, various parametric and nonparametric tests have been conducted.

The multicollinearity test result of combined data shows that the variance inflation factor for OMC and MDD is 1.924 as shown in Table 8. This shows that there is no interdependence between these two variables. The result of the

TABLE 7: Normality test result of residual for primary and secondary data.

Normality test methods		For combined (primary and secondary) data Unstandardized residual
Shapiro–Wilk	Significance	0.4707
Skewness	skewness	0.464
	Std. error of skewness	0.3366
Kurtosis	Kurtosis	0.464 0.285
	Std. error of kurtosis	0.6619

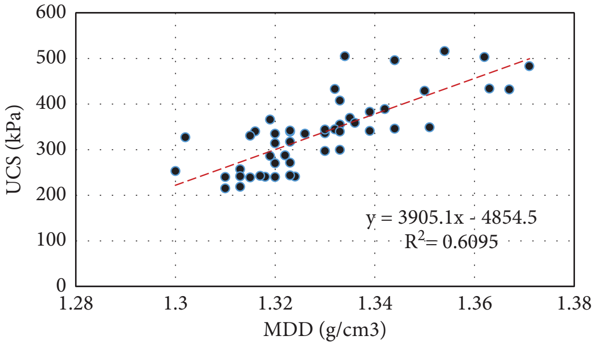

FIGURE 2: Regression graph of model 1.

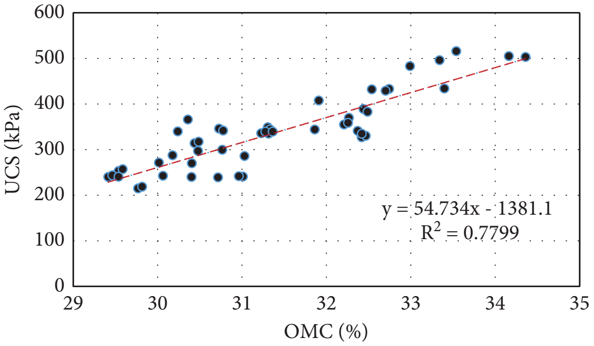

FIGURE 3: Regression graph of model 2.

independent t-test shows a t-value of 163, which is greater than the critical t-value, which is ±1.96, and the level of significance is less than 0.05. This shows that the prediction model has greater confidence in the coefficient of prediction.

The following equations were obtained from multiple linear regression analysis.

Model 3. Linear regression of UCS with MDD and OMC

The multiple linear regression analysis shows that the association of UCS with MDD and OMC is significantly strong with coefficients of correlation of 0.83.

$$\mathrm{UCS} = -3105 + 1625\,\mathrm{MDD} + 40.9\,\mathrm{OMC}\ R^2 = 0.83. \quad (5)$$

The details of the statistical output indicate that the relationship developed between UCS and compaction characteristics is statistically significant ($\alpha < 0.05$). So, predicting 83% of the variance in UCS can be accounted for by the independent variables (MDD and OMC). From the summary of multiple linear regressions, there is a good correlation between UCS with MDD and OMC rather than correlating with each of them. Prasanna et al. [27] also suggested that multiple linear regression analysis has a good correlation in estimating compaction characteristics of soils from index properties of fine-grained soils.

3.4. Validation of Prediction Models. For validation of the selected prediction model, 10 control tests which cover 20% of the training data are used. Table 9 shows the actual UCS, MDD, OMC, and the corresponding predicted value of UCS with a percentage of average variation of controlled tests. The values of predicted UCS in Table 9 are obtained using the equation (5) developed in the current study under model 4.

TABLE 8: Multicollinearity test result ($N = 50$).

Model		Coefficients	
		Collinearity statistics	
		Tolerance	VIF
1	MDD	0.520	1.924
	OMC	0.520	1.924

a. Dependent variable: UCS.

There is no existing equation developed to predict UCS from compaction parameters for Burayu town, Ethiopia, except for the current model. The result of the currently developed model is compared with the actual values of UCS used in this study. Figure 4 shows the comparison of the predicted values obtained from the developed model in equation (5) with the actual values of UCS used in the prediction. In Figure 4, a little variation has been seen between the actual and the predicted UCS values. However, the graph follows the same patterns. Some points show mismatch which may be due to certain errors during laboratory tests.

Figure 5 shows the graph plotted using actual experimental UCS and the UCS predicted by the developed correlation equation. The point at which the predicted UCS equals the experimental UCS is represented by a straight line.

Most of the points are found to be very close to the straight line. This shows that the prediction equation can be used for preliminary characterization of the unconfined compressive strength of the soil in the study area.

Table 9: Validation of the prediction model.

Sample code	Actual UCS (kPa)	MDD (g/cm^3)	OMC (%)	Predicted UCS (kPa)	Variation in (%)
C-1	275	1.31	30.5	271.2	1.4
C-2	463	1.35	33.8	471.2	1.8
C-3	370	1.34	31.9	377.2	1.9
C-4	256	1.327	29.623	263	2.7
C-5	334	1.311	32.154	340.4	1.9
C-6	446	1.346	33.627	457.6	2.6
C-7	433	1.33	34.168	453.7	4.8
C-8	268	1.302	31.012	279.1	4.1
C-9	243	1.293	30.269	234.1	3.8
C-10	344	1.324	31.621	339.8	1.2

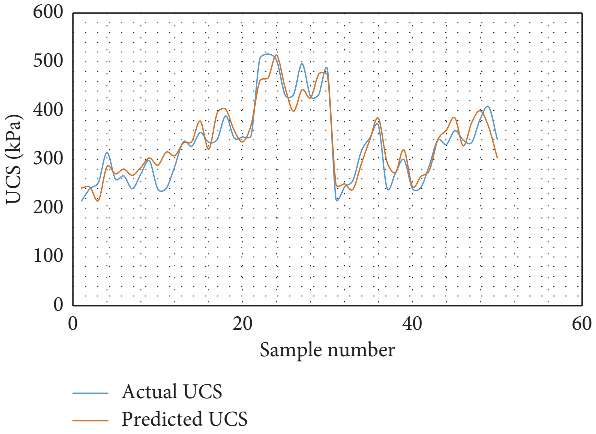

Figure 4: The comparison of predicted and actual values of UCS.

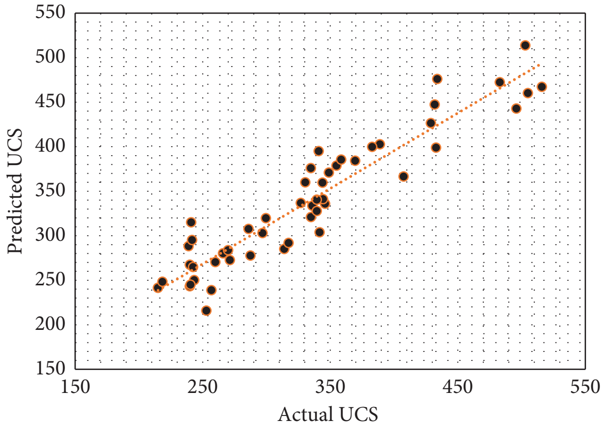

Figure 5: Graph of actual UCS plotted against predicted UCS.

4. Conclusion

The main objective of this study was to establish a correlation equation between unconfined compressive strength and compaction characteristics within the scope of the study area. The study aimed to pave the way to determine UCS from MDD and OMC where there is a limitation of the UCS machine. Fifty samples were collected from different places in Burayu town. Unconfined compressive strength, Atterberg limits, and compaction tests were carried out. Regression analysis was performed to establish the prediction equation for UCS from MDD and OMC. UCS was considered a dependent variable, while MDD and OMC were considered independent variables. Before conducting regression analysis, different parametric and nonparametric tests such as *t*-test, normality test, and multicollinearity tests were carried out to check the normal distribution of data and interdependency of the independent variables. Accordingly, the study data were found to be normally distributed and there was no interdependency between MDD and OMC. Using single linear regression, the correlation equations were developed for UCS vs. MDD and UCS vs. OMC which give fair coefficients of correlation. The correlation equation developed using multiple linear regression gave a strong coefficient of determination with $R^2 = 0.83$ ($\text{UCS} = -3105 + 1625\ \text{MDD} + 40.9\ \text{OMC}$ with $R^2 = 0.83$). The independent variables used in multiple linear regression analysis were determined to be normally distributed, not dependent on each other so that the developed model can be used for predicting UCS. The established model was validated using 10 control tests which resulted in 97% accuracy in the UCS determination for multiple regressions.

Data Availability

All data are available within the article.

Conflicts of Interest

The authors have no conflicts of interest.

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References

[1] F. Y. Fang and J. L. Daniels, *Introductory Geotechnical Engineering*, CRC Press, Boca Raton, Florida, 2010.

[2] H. Yokoi, “Relationship between soil cohesion and shear strength,” *Soil Science & Plant Nutrition*, vol. 14, no. 3, pp. 89–93, 1968.

[3] V. N. Murthy, “Geotechnical engineering: principles and practices of soil mechanics and foundation engineering,” *Jurnal Ekonomi Malaysia*, Penerbit UKM, Bangi, Malaysia, 2002.

[4] V. N. Murthy, “Foundation analysis and design fifth edition,” in *The British Journal of Psychiatry*McGraw Hill Education, New York City, 2013.

[5] K. Bláhová, L. Ševelová, P. Pilařová, and P. Pilařová, “Influence of water content on the shear strength parameters of clayey soil in relation to stability analysis of a hillside in Brno region,” *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, vol. 61, no. 6, pp. 1583–1588, 2013.

[6] I. Ishibashi and H. Hazarika, *Soil Mechanics Fundamentals and Application*, CRC Press, Boca Raton, Florida, 2010.

[7] R. Ghosh, “Effect of soil moisture in the analysis of undrained shear strength of compacted clayey soil,” *Journal of Civil Engineering and Construction Technology*, vol. 4, no. 1, pp. 23–31, 2013.

[8] H. B. Nagaraj and M. R. Suresh, “Influence of clay mineralogy on the relationship of cbr of fine-grained soils with their index and engineering properties,” *Transportation Geotechnics*, vol. 15, pp. 1–43, 2018.

[9] C. P. Wroth and D. M. Wood, “The correlation of index properties with some basic engineering properties of soils,” *Canadian Geotechnical Journal*, vol. 15, no. 2, pp. 137–145, 1978.

[10] A. Mohammed, “Property correlations and statistical variations in the geotechnical properties of (Ch) clay soils,” *Geotechnical and Geological Engineering*, pp. 1–16, 2017.

[11] S. Matsumura and F. Tatsuoka, “Effect of compaction conditions and fines content on cyclic undrained strength of saturated soils,” *Soil Dynamics and Earthquake Engineering*, vol. 112, pp. 152–161, 2018.

[12] J. Ameratunga, N. Sivakugan, and B. M. Das, *Correlations of Soil and Rock Properties in Geotechnical Engineering*, Springer India, New Delhi, India, 2016.

[13] H. Soltani-Jigheh, A. Soroush, and M. Rezaie, “Estimating undrained cyclic behavior of compacted mixed clayey soils by statistical tools” Scientia,” *Iran*, vol. 19, no. 3, pp. 346–354, 2012.

[14] A. Kebede, *Correlation between Standard Penetration Test with Unconfined Compressive Strength and Index Properties of Fine-Grained Soil, Master Thesis*, Department of Civil Engineering, Addis Ababa University, Addis Ababa, Ethiopia, 2016.

[15] C. C. Ikeagwuani, O. P. Ogbonna, and T. T. Ijioma, “Correlation between maximum dry density and cohesion of remoulded Nsukka clays,” *Nigerian Journal of Technology*, vol. 37, no. 1, pp. 13–18, 2018.

[16] D. Abdella, T. Abebe, and T. Quezon, “Regression analysis of index properties of soil as strength determinant for California bearing ratio (CBR),” *Global Scientific Journal*, vol. 5, no. 6, pp. 1–12, 2017.

[17] M. Drusa, J. Vlček, and L. Orininová, “The role of geotechnical monitoring at design of foundation structures and their verification-Part 1,” *Civil and Environmental Engineering*, vol. 12, no. 1, pp. 21–26, 2016.

[18] W. Hirpasa, *Investigation on the Engineering Properties of Soils Found in Burayu Town, Master Thesis*, Department of Civil Engineering, Addis Ababa University, Addis Ababa, Ethiopia, 2015.

[19] D. Bekele, M. Asfaw, and A. Jafri, “Causes and remedy of squatting in Burayu town, Ethiopia,” *Developing Country Studies*, vol. 4, no. 11, pp. 10–18, 2014.

[20] Astm D 1587-08, “Standard practice for thin-walled tube sampling of soils for geotechnical purposes,” in *Annual Book of ASTM Standards*, pp. 1–4, ASTM International, West Conshohocken, Pennsylvania, 2008.

[21] Astm D, “Standard practices for preserving and transporting soil samples,” in *Annual Book of ASTM Standards*, vol. 4, pp. 1–7, no. 8, ASTM International, West Conshohocken, Pennsylvania, 2007.

[22] S. Kormu and A. Sorsa, *Correlation between Compaction Characteristics with Undrained Shear Strength of Soils Found in Burayu Town*, Research square, 2021.

[23] S. Kormu, “Correlation between compaction characteristics with undrained shear strength of soils found in Burayu town,” MSc. Thesis, Jimma University, Jimma, Ethiopia, 2019.

[24] A. Sorsa, S. Senadheera, and Y. Birru, “Engineering Characterization of subgrade soils of Jimma town, Ethiopia, for roadway design,” *Geosciences*, vol. 10, no. 3, pp. 94–17, 2020.

[25] N. Draper and H. Smith, *Applied Regression Analysis. Series in Probability and Mathematical Statistics*, Wiley, Hoboken, New Jersey, 1981.

[26] L. Winner, F. A. Graybill, and H. K. Iyer, “Regression analysis-concepts and applications,” *The American Statistician*, vol. 49, no. 1, p. 114, 1995.

[27] S. Prasanna, S. Krishna, H. Krishnegowda, and S. Suhruth, “Correlation of compaction characteristics of fine-grained soils using atterberg limits,” *International Journal of Engineering & Technology*, vol. 6, no. 6, pp. 23–30, 2017.