International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

Compaction and Consolidation Characteristics of Soils and Correlations of Parameters

Bipul Sen
Assistant Professor
Civil Engineering Department, ICFAI University,Tripura, Agartala, India

Dr. Sujit Kumar Pal
Associate Professor
Civil Engineering Department, NIT Agartala, Agartala, India

ABSTRACT

This paper explores the variation of the compaction and consolidation characteristics of different soils collected from seven different locations of Agartala City, Tripura, INDIA and Laboratory tests such as specific gravity test, grain size analysis, Atterberg's limit test, standard Proctor compaction test and one-dimensional consolidation test are conducted on those soil samples in accordance with ASTM standards. Effect of plasticity index (PI) on optimum moisture content (OMC), effect of grain size on OMC and maximum dry density (MDD),effect of PI on compression index (C_c), and effect of OMC on C_c of soils have been discussed. An attempt has also been made to established regression analysis and multiple regression analysis to predict the compaction characteristics and C_c of soil. Correlations have been established on regression analysis and on multiple regression analysis to assess OMC, MDD and C_c. From the experimental study, it is observed that the values OMC, MDD and C_c of such soil samples lie within the range of 14.00 to 22.10%, 13.86 to 17.95 kN/m^3 and 0.11 to 0.159 respectively. Also found that with the increase in PI and finer fraction (i.e., clay and silt), OMC increases and MDD decreases, and with the increase in PI, OMC and finer fraction (FF), C_c increases. The values of the coefficient of determination (R^2) lie within the range of 0.800 to 0.997 and 0.946 to 0.992 for regression analysis and multiple regression analysis respectively. The errors in the predicted values of OMC (%), MDD (kN/m^3) and C_c, verified with the test results of previous studies are within the range of −9.57% to +13.30% in case of regression analysis and −7.14 to +7.27% in case of multiple regression analysis. Hence, these empirical relations would be useful for the engineers in the field to satisfy the quality control as well as for preliminary design and estimation. From the study, values of OMC in low land areas is comparatively higher than the ridge land areas and the values of MDD in ridge land areas is comparatively higher than the low land areas. By knowing the OMC, MDD and C_c from regression analysis, without doing tests the values can be implemented in the field directly.

KEYWORDS

Soils, Optimum moisture content, Maximum dry density, Compression index, Regression analysis.

INTRODUCTION

Compaction and consolidation are the most important activities in the early stages of construction in order to improve the engineering properties of soils. The physical and engineering properties of existing soils are intrinsic and can be used as a frame of reference for the behavior of strength characteristics of soil. To predict the probable settlement of the structure on soil, it is necessary to make a comprehensive study of the compressibility and compaction characteristics of existing soil. In practical field, it is difficult to carry out all types of experiments due to lack of time and cost considerations. Empirical relationships between the properties of soil are generally sought for preliminary design and planning of quality control programme to be implemented in the construction site. Compressibility characteristics of a soil can be correlated to different characteristic properties, such as the liquid limit, the plasticity index, the natural water content, the void ratio etc., whereas the compaction parameters depends on the grain size, the liquid limit, the plasticity index, amount and method of compaction etc.

In this present study, seven different types of soil are collected from different locations of Agartala City i.e., NIT Agartala, Ranir bazar, College Tilla, GB bazar, Sakuntala Road, Dukli and Battala road. Laboratory tests such as specific gravity test, grain size analysis, Atterberg's limits test, standard Proctor compaction test and one-dimensional consolidation test are conducted on those soil samples in accordance with ASTM standards. Large numbers of studies are conducted by the previous researchers to find out different physical and engineering behavior of different soils.

Nath and Dalal (2004) has assessed physical and engineering properties of different soil and reported that due to increase of liquid limit, plasticity index of soil increases and frictional angle decreases. Kaniraj and Havanagi (2001), Bera et al. (2007) have also estimated the physical and engineering behavior of different soils. Pal and Ghosh (2011) reported that MDD values vary with initial void ratio (e_i) values. Johnson and Sallberg (1960) suggested a chart to determine the approximate OMC of different soil. Brooks et al. (2011) presented one-way analysis of variance for compaction characteristics of soil stabilized with lime stone dust and coal fly ash. Pal and Ghosh (2010) studied the influence of physical properties on engineering properties of class F fly ash and concluded that with the increase in specific gravity of fly ash, MDD increases; the values of MDD are lower and those of OMC are higher, and the values of hydraulic conductivity are higher for coarse-grained fly ash samples compared to fine-grained samples. Jesmani et al. (2008) carried out an investigation on clayey gravels at different compactive efforts for the determination of OMC and MDD and observed that OMC and MDD hold a linear relationship with log E (compactive efforts). Previous authors like, Jumikis (1958), Hilf (1956), Ring et al. (1962), Ramiah et al. (1970), and Wang and Huang (1984) have described methods to estimate the optimum water content and maximum dry unit weight of clayey soils. In most of these methods, index properties are used to estimate the optimum point for a given compactive effort. Correlation between compression index and liquid limit for all types of clay soils have been proposed by Terzaghi and Peck (1967). Nakase et al. (1988) performed a large number of tests and estimated constitutive parameters of soil by using plasticity index. Kumar and Sudha Rani (2011) have made an attempt to model compression index in terms of fine fraction, liquid limit, plasticity index, MDD and OMC using artificial neural networks (ANN). Jumikis (1958) also reported methods to estimate the OMC and MDD of fine grained soils for compaction. Sridharan and Nagaraj (2000) carried out an investigation on remolded soil and found that coefficient of consolidation had a better correlation with the shrinkage index, which is the difference between liquid limit and shrinkage limit. Giasi et al. (2003) evaluated of compression index of remolded clays by means of Atterberg's limit and concluded that the most reliable equation correlates C_c with the shrinkage index. Sudha et al. (2013) also carried out an investigation to predict the engineering properties by using artificial neural networks (ANN). Isik (2009) estimated the swell index of fine grained soils using regression equations and artificial neural networks. Skempton's relationship (1944) between compression index (C_c) and liquid limit for the remolded clays was well known. Another popular relationship between compression index and initial void ratio (e_0) had been proposed by Nishida (1956).

METHODOLOGY

Four separate models by regression analysis and three models by multiple regression analysis have been developed to correlate physical properties with compaction and compressibility characteristics of soil. These models are analyzed to obtain correlation equations. Correlations established based on the regression analysis are in the form of linear as well as non-linear are to assess OMC as function of PI, MDD as function of OMC, C_c as function of PI as well as function of OMC respectively. Correlations also established in the form of linear by multiple regression analysis to assess OMC, MDD and C_c as function of PI, FF; PI, CF and PI, OMC and FF respectively. Coefficients of determination (R^2) have been obtained to justify the correlations and the errors in the predicted values of OMC (%), MDD (kN/m^3) and C_c, also verified with the test results of previous studies.

RESULTS AND DISCUSSIONS

A. Results

The results of physical properties, i.e., specific gravity, liquid limit, plastic limit, plasticity index and grain size, and engineering properties, i.e., compaction characteristics (OMC and MDD), consolidation characteristics (compression index (C_c)) of seven different types of soil samples, collected from different locations of Agartala, Tripura, INDIA are studied in this investigation.

Soils collected from NIT Agartala, Ranir bazar, College Tilla, GB bazar, Sakuntala Road, Dukli and Battala has inorganic clay of low to medium plasticity with plasticity index 5.36 to 17.00%. Clay, silt and sand vary from 20.00 to 43.56%, 23.50 to 49.80% and 6.64 to 56.50% respectively. The values of physical properties are summarized in Table 1.

Table 1: Specific Gravity (G), Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI) and Grain Size for soils

Properties	NIT Agartala Soil	Ranir Bazar Soil	GB Bazar Soil	College Tilla Soil	Sakuntala Road Soil	Dukli Soil	Battala Soil
Specific Gravity (G)	2.58	2.57	2.55	2.61	2.56	2.50	2.53
Liquid Limit (LL) (%)	23.00	29.90	27.38	37.50	25.30	41.70	35.20
Plastic Limit (PL) (%)	17.64	17.30	14.88	21.29	18.09	24.70	20.66
Plasticity Index (PI) (%)	5.36	12.60	10.50	16.21	7.21	17.00	14.54
Grain Size (%)							
Sand, 4.75 -0.075 mm	56.50	29.00	39.25	26.85	46.15	6.64	27.55
Silt, 0.075 -0.002 mm	23.50	42.50	36.25	41.15	31.73	49.80	42.45
Clay, <0.002 mm	20.00	28.50	24.50	32.00	22.12	43.56	30.00

Soils collected from NIT Agartala, Ranir bazar, College Tilla, GB bazar, Sakuntala Road, Dukli and Battala has optimum moisture content (OMC) and maximum dry density (MDD) values 14.00, 17.80, 16.60, 19.30, 14.50, 22.10, 18.50% and 17.95, 16.97, 17.46, 16.28, 17.76, 13.86, 16.68 kN/m^3 respectively. The values of compression indices (C_c) of those locations are 0.11, 0.132, 0.124, 0.146, 0.115, 0.159 and 0.136 respectively. The values of engineering properties are summarized in Table 2.

Table 2: Optimum moisture content (OMC), Maximum dry density (MDD), Compression Index (C_c) for different types of soil

Soil Properties	NIT Agartala Soil	Ranir Bazar Soil	GB Bazar Soil	College Tilla Soil	Sakuntala Road Soil	Dukli Soil	Battala Soil
Optimum Moisture Content (OMC) (%)	14.00	17.80	16.60	19.30	14.50	22.10	18.50
Maximum Dry Density (MDD) (kN/m^3)	17.95	16.97	17.46	16.28	17.76	13.86	16.68
Compression Index (C_c)	0.11	0.132	0.124	0.146	0.115	0.159	0.136

B. Discussions

Based on above test results, the following discussions have been made in this section. Effect of plasticity index on optimum moisture content, effect of grain size on optimum moisture content and maximum dry density, effect of plasticity index on compression index, effect of optimum moisture content on compression index of soils are discussed herein.

a. Effect of plasticity index (PI) on optimum moisture content (OMC) of soils

Tables 1 and 2 showed that plasticity index (PI) and optimum moisture content (OMC) of such soil samples, lies within the range of 5.36 to 17.00% and 14.00 to 22.10% respectively. From the present study it is observed that OMC values depend on PI values of soil. Plasticity index of any soil depends upon the water attraction capacity of that soil (Al-Khafaji and Andersland 1992). When the percentage of clay particles in the soil samples increases, the OMC of the soil get increases. It is due to increase of inter-molecular attraction force within the soil particles. Due to increase of attraction force, liquid limit of the soil increases and accordingly plasticity index increases (Nath and Dalal 2004). In this present study, the PI values of Dukli, College Tilla, Battala and Ranir bazar soil samples are comparatively higher than the other locations within the Agartala city. Hence, the OMC of the soil samples of those locations are comparatively higher.

b. Effect of grain size on optimum moisture content (OMC) and maximum dry density (MDD) of soils

From Tables 1 and 2, it is observed that percentages of clay, silt and sand vary from 20.00 to 43.56%, 23.50 to 49.80% and 6.64 to 56.50% respectively. OMC and MDD vary from 14.00 to 22.10% and 13.86 to 17.95 kN/m^3 respectively for all soil samples collected from different locations of Agartala city. From Tables 1 and 2, it is revealed that OMC and MDD values of any soil sample depend on grain size of soil. A well-graded soil consists of a wide range of particle sizes with the smaller particles filling voids between larger particles which results a dense structure. As a result the densities of such soils are higher. When the sand content in the soil increases, the intermolecular attraction force (adhesion or cohesion) within the soil particles is decreases. Hence, the water attraction capacity of the soil mass is also reduces and density increases. With the increase in percentage of fine particles inter-molecular attraction force (adhesion or cohesion) within the soil particles is increases. As a result, the water attraction capacity also becomes higher and OMC increases, MDD decreases. Since, well-graded sand attains a much higher density than a poorly graded soil. Pal and Ghosh (2010) have also obtained the same trend. Several authors like, Jumikis (1958), Hilf (1956), Ring et al. (1962), Ramiah et al. (1970), and Wang and Huang (1984) have estimated the OMC and MDD on the basis of index properties.

c. Effect of plasticity index (PI) on compression index (C_c) of soils

Tables 1 and 2 showed that plasticity index (PI) and compression index (C_c) of soil samples lies within the range of 5.36 to 17.00% and 0.11 to 0.159 respectively. From Fig. 3, it is cleared that compression index of soil gets increases with the increase in plasticity index, as liquid limit increases. Since, the Atterberg's limit reflects the composition of soils and the interaction of particles with pore water (Nakase et al., 1988; Pandian and Nagaraj, 1990), the plasticity index can be considered to be a measure of the quantity of water attracted by these particles for a given value of undrained shear strength thus making it possible to correlate this parameter with the compressibility. Compression index of soil depends on the plasticity characteristics and density of soil. Plasticity is the property by which the material can undergo large amount of deformation; clay exhibits this property to a greater degree with high liquid limit. That is why, soil containing high liquid limit, posses high plasticity index gives a higher compression index. Similar trend for clays was observed by Terzaghi and Peck (1967), Sridharan and Nagaraj (2000) and Bowles (1996).

d. Effect of optimum moisture content (OMC) on compression index (C_c) of soils

Table 2 showed that optimum moisture content and compression index of all the soil samples collected from different locations lies within the range of 14.00 to 22.10% and 0.11 to 0.159 respectively. Fig. 4 represents a relationship between OMC and C_c. From this figure, it is clear that compression index of soil increases with the increase of OMC of soil. With the increase of OMC, the amount of voids (in the form of pore water) in soil gets increase and dry density gets decrease and under loading condition expulsion of that pore water

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

occurs and as a result compressibility of soil gets increases. Pal and Ghosh (2011) was observed similar trend in case of fly ash. Firm relationship between OMC and C_c found out, as compression index as well as OMC also controlled by composition, structure and moisture attraction capacity of soil (Terzaghi and Peck 1967).

REGRESSION ANALYSIS

Regression analysis is a statistical tool for the investigation, calculate and interpret the simple relationships between dependent variable and independent variables. In this paper attempts have been made to develop a mathematical relationship between two and more variables by fitting a linear and non-linear equation on observed test data. Assessment of regression relationships can be done through estimation of coefficient of determination (R^2). It is the ratio of regression sum of squares to total sum of squares. R^2 lies between 0 and 1. The closer it is to 1, the better is the equation (Draper and Smith 1998). Haan (1994) stated that the quality of a regression relationship depends on the ability of the relationship to predict the dependent variable for observation on the independent variables that were not used in estimating the regression coefficients. In this paper four models have been developed by regression analysis and three models by multiple regression analysis.

The proposed models by regression analysis are

Model 1: PI vs. OMC;

Model 2: OMC vs. MDD;

Model 3: PI vs. C_c; and

Model 4: OMC vs. C_c.

The correlations generated by these models are shown in Figs. 1 to 4 and in Tables 3 to 6.

Models used for multiple regression analysis are

Model 1: PI and Percentage of finer fraction (clay and silt, i.e., FF) vs. OMC;

Model 2: PI and Percentage of coarser fraction (sand, i.e., CF) vs. MDD; and

Model 3: PI**,** OMC and Percentage of finer fraction (clay and silt, i.e., FF) vs. C_c.

The correlations generated by these models are shown Tables 7 to 9.

A. Correlations Between Different Parameters By Simple Regression Analysis

In the following section various empirical correlations have been developed by the regression analysis between different parameters based on different properties of soil. Geotechnical properties of seven different types of soil of different location of Agartala City have been determined in the laboratory in accordance with relevant ASTM standards to develop relationships between the index and engineering properties. The relationships have also been validated with the data obtained from past studies. Errors in predicted values based on results of earlier studies are tabulated in this paper.

a. Relationship between plasticity index (PI) and optimum moisture content (OMC) of soils

Correlations (Model 1) have developed between PI (%) and OMC (%) in the form of linear, exponential, polynomial, logarithmic and power curves have been developed to assess OMC (%) based on present test results of all the seven different types of soil samples collected from seven different locations of Agartala City and are represented through the following equations:

$$OMC = 0.608(PI) + 10.29 \quad (1)$$

$$OMC = 11.39e^{0.035PI} \quad (2)$$

$$OMC = 0.028(PI)^2 - 0.022PI + 13.34 \quad (3)$$

$$OMC = 6.038\ln(PI) + 3.019 \quad (4)$$
$$OMC = 7.422(PI)^{0.353} \quad (5)$$

The above equations are valid for the values of PI within the range of 5.36 to 17.00%. The values of the relevant statistical coefficients like, coefficient of determination (R^2) are 0.925, 0.953, 0.944, 0.869 and 0.912 for equations (1), (2), (3), (4) and (5) respectively. The present relationships have been verified with the results of earlier researchers. Details of the observed and predicted values along with errors in percentage have been shown in Table 3. The errors in the values of OMC obtained from equations (1) to (5) are within the range of −5.01 to +9.60%, − 6.19 to +8.20%, −7.54 to + 6.53%, −1.81 to +13.3% and −2.87 to +12.00% respectively for the test results of previous studies used for validation. The curves for the corresponding equations are presented in Fig.1.

b. Relationship between optimum moisture content (OMC) and maximum dry density (MDD) of soils

Empirical relationships (Model 2) have been developed between OMC (%) and MDD (kN/m^3) in the form of linear, polynomial, logarithmic and power curves by using the test results of all the seven different types of soil samples collected from seven different locations of Agartala City which are represented through the following equations to assess MDD:

$$MDD = -0.462(OMC) + 24.82 \quad (6)$$

$$MDD = -7.86\ln(OMC) + 39.15 \quad (7)$$

$$MDD = -0.062(OMC)^2 + 1.776(OMC) + 5.295 \quad (8)$$

$$MDD = 67.55(OMC0^{-0.49} \quad (9)$$

The above equations are valid for the values of OMC within the range of 14.00 to 22.10%. The values of the relevant statistical coefficients like, coefficient of determination (R^2) are 0.879, 0.997, 0.827 and 0.800 for equations (6), (7), (8) and (9) respectively. Details of the observed and predicted values along with errors in percentage have been shown in Table 4. The errors in the values of MDD obtained from equations (6) to (9) are within the range of −3.54 to +4.00%, − 3.76 to −4.41%, −2.23 to +6.03%, −3.93 to +4.20% respectively for the test results of previous studies used for validation. The curves for the corresponding equations are presented in Fig.2.

c. Relationship between plasticity index (PI) and compression index (C_c) of soils

Correlations (Model 3) have developed between PI (%) and C_c in the form of linear and power curves have been developed to assess Compression Index (C_c) based on present test results of all the seven different types of soil samples collected from seven different locations of Agartala City and are represented through the following equations:

$$C_c = 0.003(PI) + 0.087 \quad (10)$$

$$C_c = 0.066(PI)^{0.283} \quad (11)$$

The above equations are valid for the values of PI within the range of 5.36 to 17.00%. The values of the relevant statistical coefficients like, coefficient of determination (R^2) are 0.931 and 0.899 for equations (10) and (11) respectively. The present relationships have been verified with the results of earlier researchers. Details of the observed and predicted values along with errors in percentage have been shown in Table 5. The

ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

errors in the values of MDD obtained from equations (10) and (11) are within the range of −7.69 to +5.83% and 0.00 to +8.33% respectively for the test results of previous studies used for validation. The curves for the corresponding equations are presented in Fig. 3.

d. Relationship between optimum moisture content (OMC) and compression index (C_c) of soils

Empirical relationships (Model 4) have been developed between OMC (%) and C_c in the form of linear and power curves by using the test results of all the seven different types of soil collected from seven different locations of Agartala City which are represented through the following equations to assess compression index:

$$C_c = 0.006(OMC) + 0.024 \tag{12}$$

$$C_c = 0.013(OMC)^{0.808} \tag{13}$$

The above equations are valid for the values of OMC within the range of 14.00 to 22.10%. The values of the relevant statistical coefficients like, coefficient of determination (R^2) are 0.986 and 0.985 for equations (12) and (13) respectively. The present relationships have been verified with the results of earlier researchers. Details of the observed and predicted values along with errors in percentage have been shown in Table 6. The errors in the values of C_c are within the range of −9.57 to +5.45% and −7.86 to +7.27% for the equations (12) and (13) respectively .The curves for the corresponding equations are presented in Fig.4.

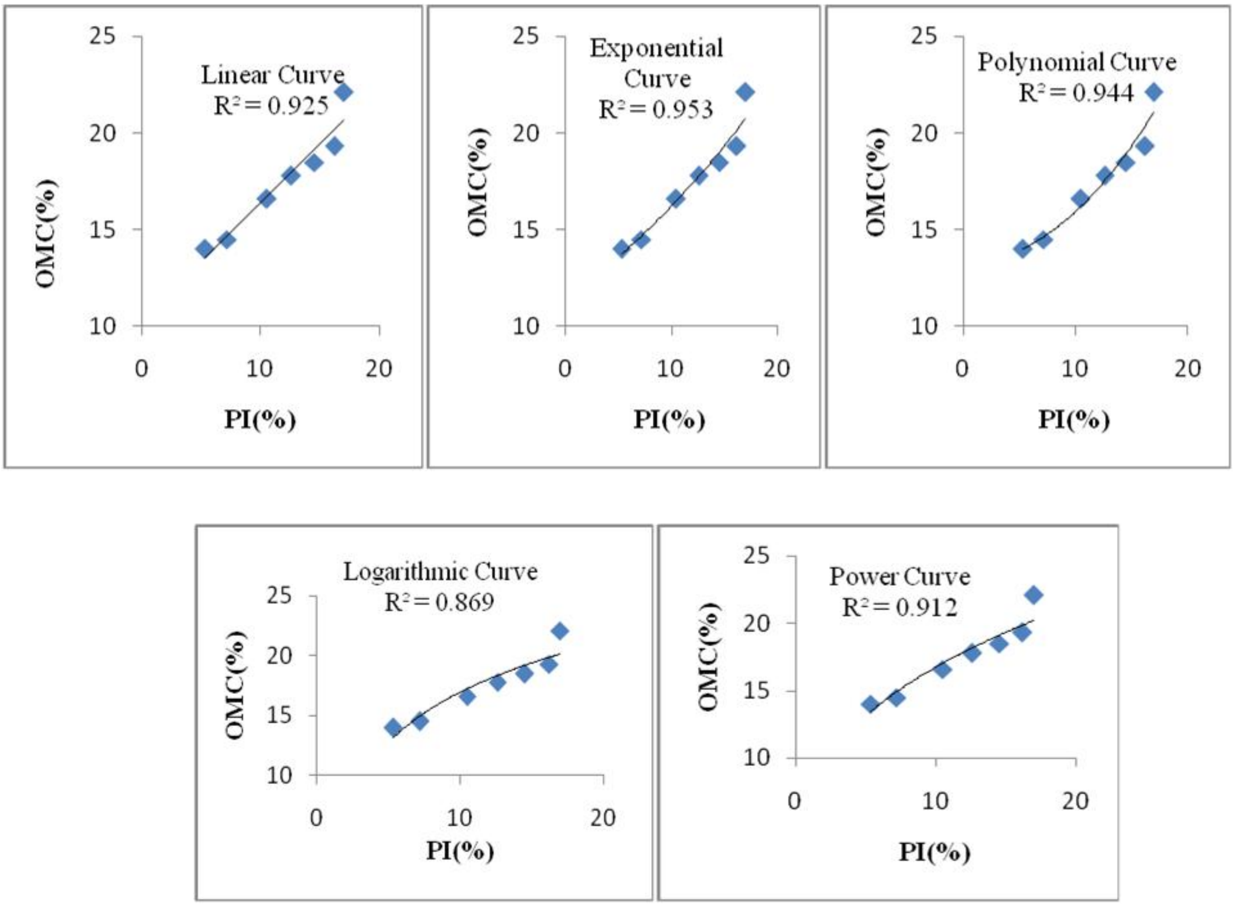

Fig. 1: Relationship between optimum moisture content (OMC) and plasticity index (PI) of soils

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

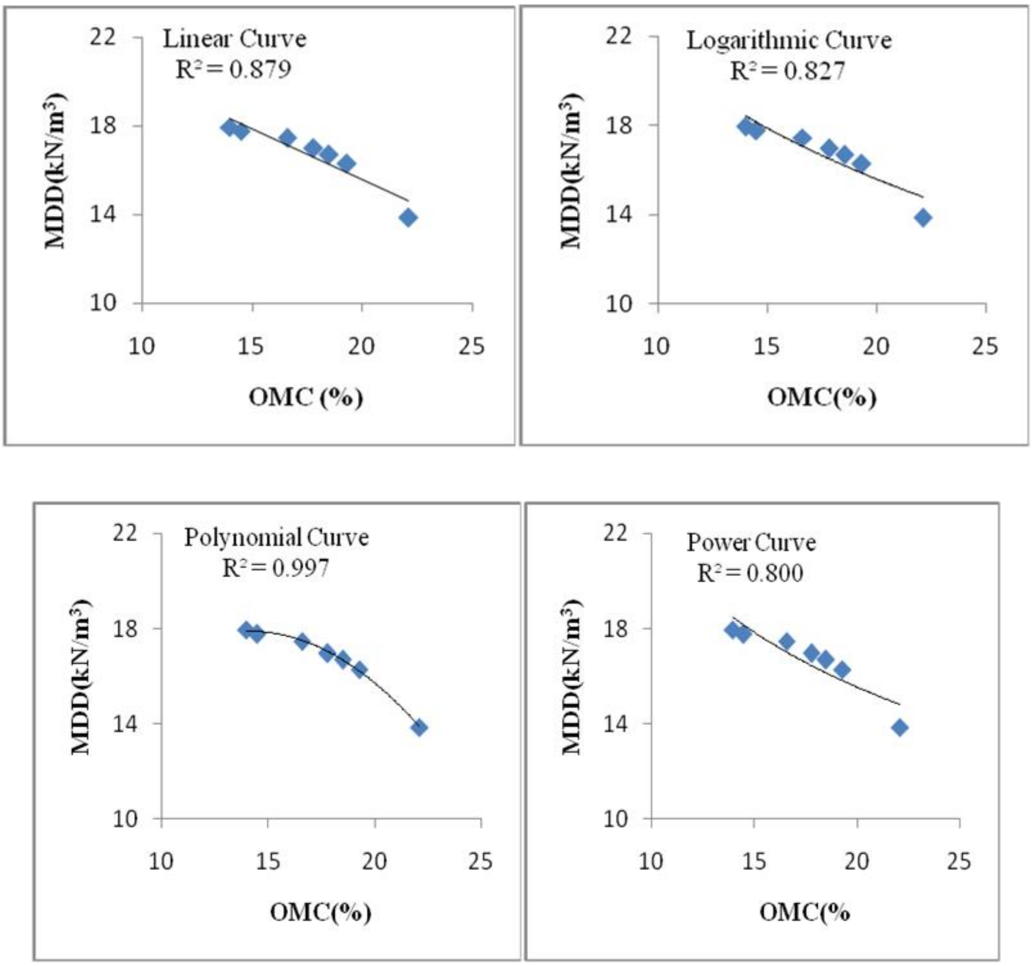

Fig. 2: Relationship between maximum dry density (MDD) and optimum moisture content (OMC) of soils

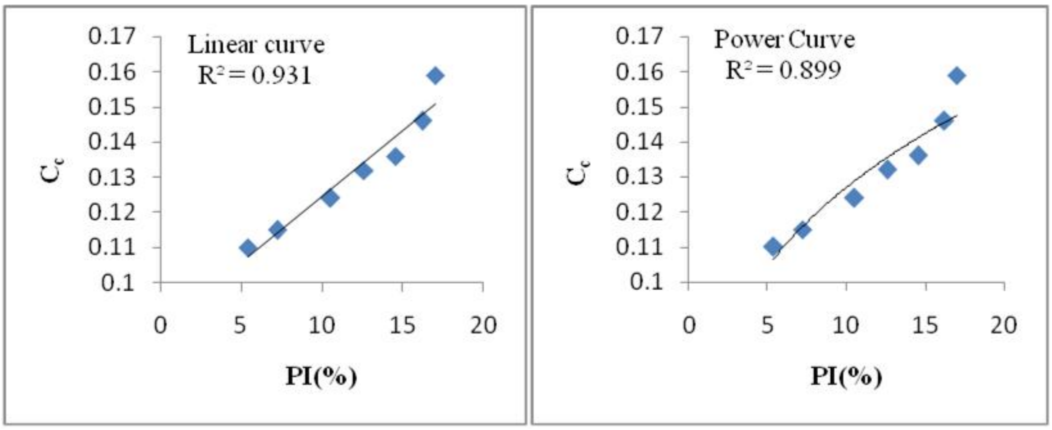

Fig. 3: Relationship between compression index (C_c) and plasticity index (PI) of soils

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

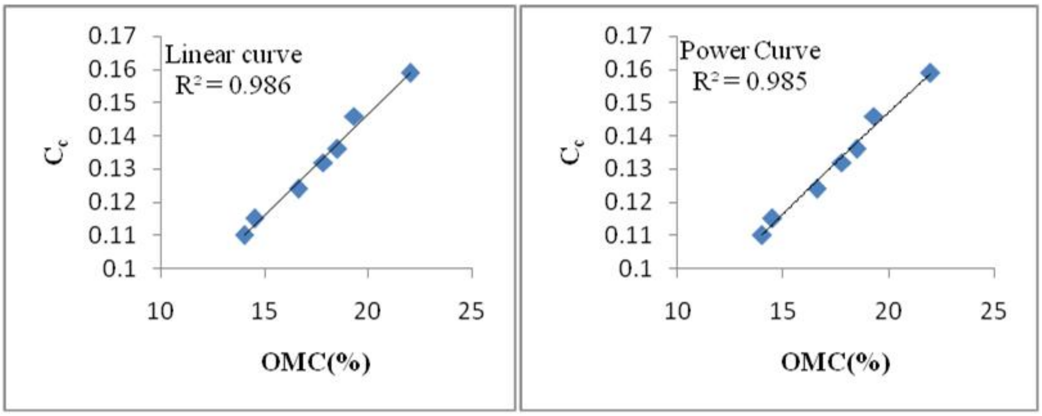

Fig.4: Relationship between compression index (C_c) and optimum moisture content (OMC) of soils

Table 3: Observed and predicted values based on Equations (1) to (5)

Reference	Observed values		Predicted values				
	OMC (%)	PI (%)	Eq.(1)	Eq.(2)	Eq.(3)	Eq.(4)	Eq.(5)
Gunaydin (2009)	18.20	14.05	18.83 (+3.46)	18.62 (+2.31)	18.56 (+1.97)	18.97 (+4.23)	18.86 (+3.6)
Laskar and Pal (2012)	20.00	16.31	20.20 (+1.00)	20.15 (+0.75)	20.42 (+2.10)	19.88 (-0.62)	19.88 (-0.62)
	17.10	9.79	16.24 (-5.01)	16.04 (-6.19)	15.81 (-7.54)	16.79 (-1.81)	16.61 (-2.87)
Singh(2012)	15.00	10.12	16.44 (+9.60)	16.23 (+8.20)	15.98 (+6.53)	16.99 (+13.3)	16.8 (+12.0)
Abbasi et al. (2012)	19.50	14.50	19.11 (-2.00)	18.92 (-2.97)	18.91 (-3.03)	19.17 (-1.69)	19.07 (-2.20)

Note: Number in parenthesis indicates error in the predicted value in percentage in comparison with the observed value.

Table 4: Observed and predicted values based on Equations (6) to (9)

Reference	Observed values		Predicted values			
	MDD (kN/m^3)	OMC (%)	Eq.(6)	Eq.(7)	Eq.(8)	Eq.(9)
Saha and Pal (2012)	18.35	15.4	17.70 (-3.54)	17.66 (-3.76)	17.94 (-2.23)	17.69 (-3.59)
Kumar.V.Dr(2004)	14.75	20.5	15.34 (+4.0)	15.40 (+4.41)	15.64 (+6.03)	15.37 (+4.20)
Lisa et al.(1998)	16.70	18	16.54 (-0.96)	16.43 (-1.60)	17.17 (+2.81)	16.39 (-1.86)
Daniel and Benson (1990)	17.30	17.5	16.74 (-3.23)	16.65 (-3.76)	17.39 (+0.52)	16.62 (-3.93)

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

Note: Number in parenthesis indicates error in the predicted value in percentage in comparison with the observed value.

Table 5: Observed and predicted values based on Equations (10) and (11)

Reference	Observed values		Predicted values	
	C_c	PI (%)	Eq.(10)	Eq.(11)
Laskar and pal (2012)	0.11	5.56	0.104 (−5.45)	0.11(0.0)
Akayuli and Ofosu (2013)	0.124	12.4	0.124 (0.0)	0.13 (+4.83)
	0.12	13.4	0.127 (+5.83)	0.13 (+8.33)
	0.13	10.2	0.12(−7.69)	0.13 (0.0)

Note: Number in parenthesis indicates error in the predicted value in percentage in comparison with the observed value.

Table 6: Observed and predicted values based on Equations (12) to (13)

Reference	Observed values		Predicted values	
	C_c	OMC (%)	Eq. (12)	Eq. (13)
Laskar and pal (2012)	0.11	15.40	0.116 (+5.45)	0.118 (+7.27)
	0.14	17.10	0.126 (−9.57)	0.129 (−7.86)
Sudha Rani(2013)	0.106	14.50	0.11 (+3.77)	0.11 (+3.77)

Note: Number in parenthesis indicates error in the predicted value in percentage in comparison with the observed value.

B. Correlations Between Different Parameters By Multiple Regression Analysis

Three models with different combinations of soil properties were analyzed by multiple regression analysis for the correlation of a combination of different soil properties with OMC, MDD and C_c. The results of the multiple regression analysis were obtained in the form of correlation equations and statistical parameter like, coefficient of determination (R^2) value. The relationships have also been validated with the data obtained from past studies. Errors in predicted values based on results of earlier studies are tabulated in this paper. The following sections represent the empirical relationships based on the multiple regression analysis.

Correlations developed between different parameters by multiple regression analysis are represented through the following equations:

$$OMC = 6.171576 + 0.257326(PI) + 0.121571(FF) \quad (14)$$

$$MDD = 11.29736 + 0.112518(PI) + 0.127922(CF) \quad (15)$$

$$C_c = 0.025532 + 0.000319(PI) + 0.006292(OMC) - 0.00012(FF) \quad (16)$$

The values of the relevant statistical coefficients like, coefficient of determination (R^2) are 0.992, 0.946 and 0.981 respectively for the observed multiple regression analysis model. The errors in the predicted values of OMC, MDD and C_c are within the range of −6.61 to +3.49%,−1.55 to +5.81% and of −7.14 to +7.27% for the equations (14) to (16) respectively.

Table 7: Observed and predicted values based on Equation (14)

Reference	Observed values			Predicted values
	OMC (%)	**PI (%)**	**FF (%)**	**Eq.(14)**
Laskar and pal (2012)	20.00	16.31	74.15	19.38(−3.10)
	17.10	9.79	59.85	15.97(−6.61)
Gunaydin (2008)	16.30	14.48	59.00	16.87(+3.49)
	17.90	16.91	64.00	18.08(+1.00)

Note: Number in parenthesis indicates error in the predicted value in percentage in comparison with the observed value.

Table 8: Observed and predicted values based on Equation (15)

Reference	Observed values			Predicted values
	MDD(kN/m^3)	**PI (%)**	**CF (%)**	**Eq.(15)**
Gunaydin (2009)	16.53	16.91	36.00	17.49(+5.81)
	18.04	14.48	41.00	18.16(+0.67)
Saha and pal (2012)	18.35	5.56	54.74	18.92(+3.11)
Laskar and pal (2012)	16.70	16.31	25.85	16.44 (−1.55)
	17.60	9.79	40.15	17.53 (−0.40)

Note: Number in parenthesis indicates error in the predicted value in percentage in comparison with the observed value.

Table 9: Observed and predicted values based on Equation (16)

Reference	Observed values				Predicted values
	C_c (%)	**PI (%)**	**OMC (%)**	**FF (%)**	**Eq.(16)**
Laskar and pal(2012)	0.11	5.56	15.40	45.26	0.118 (+7.27)
	0.14	9.79	17.10	59.85	0.13 (−7.14)

Note: Number in parenthesis indicates error in the predicted value in percentage in comparison with the observed value.

CONCLUSIONS

Based on the above test results and discussions the following conclusions may be made:

- With the increase in the plasticity index and finer fraction (i.e., clay and silt), the value of OMC of the soil increases and MDD decreases.
- With the increase in the coarse-fraction (i.e., sand), the value of MDD increases.
- With the increase in the finer-fraction (i.e., clay and silt), plasticity Index and optimum moisture content of the soil, the compression index increases.
- The values of OMC and MDD of soils of Agartala City, Tripura, INDIA lies within the range of 14.00 to 22.10% and 13.86 to 17.95 kN/m^3 respectively.

- The values of C_c of soils of Agartala City, Tripura, INDIA lies within the range of 0.11 to 0.159.
- The values OMC in low land areas is comparatively higher than the ridge land areas, but the values MDD in ridge land areas is comparatively higher than the low land areas.
- The value of the coefficient of determination (R^2) is near about 1.0 for all the equations established.
- The empirical relationships for OMC as function of PI have been developed in the form of linear, exponential, polynomial, logarithmic and power equations. The error in the predicted values of OMC (%), verified with the previous studies are within the range of −7.54% to +13.30%.
- The empirical relationships for MDD as function of OMC have been developed in the form of linear, polynomial, logarithmic and power equations. The error in the predicted values of MDD (kN/m^3), verified with the previous studies are within the range of −3.93 to +6.03%.
- The empirical relationships for C_c as function of PI have been developed in the form of linear and power equations. The errors in the predicted values of C_c, verified with the previous studies are within the range of −7.69 to +8.33%.
- The empirical relationships for C_c as function of OMC have been developed in the form of linear and power equations. The errors in the predicted values of Cc, verified with the previous studies are within the range of −9.57% to +7.27%.
- Results of linear multiple regression analysis of three models shows good correlations. The values of R^2 for all the three models are 0.992, 0.946 and 0.981, which exhibit good correlations. Therefore, it can be concluded that a combination of soil properties viz., PI and grain size, correlate well with engineering properties as compared to an individual soil properties.
- The empirical relationship for OMC as function of PI, FF has been developed in the form of linear. The errors in the predicted values of OMC (%), verified with the previous studies are within the range of −6.61 to +3.49%.
- The empirical relationship for MDD as function of PI, CF has been developed in the form of linear. The errors in the predicted values of MDD (kN/m^3), verified with the previous studies are within the range of −1.55 to +5.81%.
- The empirical relationship for C_c as function of PI, OMC and FF has been developed in the form of linear. The errors in the predicted values of C_c, verified with the previous studies are within the range of −7.14 to +7.27%.
- Since the percentage of errors are very less, hence these empirical relations would be useful for the engineers in the field to satisfy the quality control as well as for preliminary design and estimation.

REFERENCES

1. Abbasi, N., Javadi, A.A. and Bahramloo, R. 2012. Prediction of Compression Behavior of Normally Consolidated Fine-Grained Soils, World Applied Sciences journal, 18(1), 6-14.
2. Al-Khafaji, A. W. N., and Andersland, O. B. 1992. Equations for compression index approximation, J. Geotech Engg., ASCE, 118(1), 148–153.
3. Bera, A. K., Ghosh, A., and Ghosh, A. 2007. Compaction characteristics of pond ash, J. Mat. Civil Engg, ASCE, 19(4), 349–357.
4. Blotz, B.L.R.,Benson, C.H. and Boutwell, G.P. 1998. Estimating Optimum Water Content and Maximum Dry Unit Weight for Compacted Clays, Journal of Geotechnical and Geo environmental Engineering, ASCE, 124(9), 907-912.
5. Bowles, J. E. 1996. Physical and geotechnical properties of soils, McGraw-Hill international editions.
6. Daniel, D., and Benson, C. 1990. Water content-density criteria for compacted soil liners. J. Geotech. Engrg., ASCE, 116(12), 11811130.
7. Draper, N. R. and Smith, H. 1998. Applied regression analysis, John Wiley and Sons, New York.
8. Giasi, C.I., Cherubini, C. and Paccapelo, F. 2003. Evaluation of compression index of remoulded clays by means of Atterberg limits, Bull Engg. Geol. Env. 62, 333–340.
9. Gunaydin, O. 2009. Estimation of soil compaction parameters by using statistical analyses and artificial neural networks, Environ. Geol. 57, 203–215.
10. Haan, C. T. 1994. Statistical methods in hydrology, Affiliated East-West Press Pvt. Ltd., New Delhi, India.

11. Hilf, J. 1956. A rapid method of construction control for embankments of cohesive soil. Engrg. Monograph No. 26, U.S. Bureau of Reclamation, Denver, Colo.
12. Izik, N.S.2009. Estimation of swell index of fine grained soils using regression equations and artificial neural networks, Scientific Research and Essay, 4 (10), 1047-1056.
13. Jesmani, M., Manesh, A.N. and Hoseini, S.M.R.2008. Optimum Water Content and Maximum Dry Unit Weight of Clayey Gravels at Different Compactive Efforts, EJGE, 13, 1-14.
14. Johnson, A.W. and Sallberg, J. R. 1960. Factors that influence field compaction of soils compaction characteristics of field equipment, Highway Res. Board Bull 272:14.
15. Jumikis, A. R. 1946. Geology and soils of the Newark (NJ) metropolitan area, J. Soil Mech. Found., ASCE, 93(2), 71–95.
16. Jumikis, A. R. 1958.Geology and soils of the Newark (NJ) metropolitan area, J. Soil Mech. Found. Div. 94(2).
17. Kaniraj, S. R., and Havanagi, V. G. 2001. Correlation analyses of laboratory compaction of fly ashes, J. Practice Periodical of Hazardous, Toxic and Radioactive Waste Management, ASCE, 5(1), 25–32
18. Kumar, V. P. and Sudharani, C. H. 2001. Prediction of compression index of soils using artificial neural networks (anns), International Journal of Engineering Research and Applications, 1(4), 1554–1558.
19. Kumar, V. 2004. Compaction and permeability study of pond ash amended with locally available soil and hardening agent, Journal of The Institution of Engineers (India), vol 85, no.1.
20. Laskar, A. and Pal, S.K. 2012. Geotechnical Characteristics of Two Different Soils and their Mixture and Relationships between Parameters, EJGE, 17, 2821- 2832.
21. Lisa R. Blotz,I Craig H. Benson,1 and Gordon P. Boutwell. (1998) "Estimating optimum water content and maximum dry unit Weight for compacted clays." Journal of Geotechnical and Geo environmental engineering, 124, 907-912.
22. Nader, A., javadi, A. A. and Bahramloo, R. 2012. Prediction of compression behavior of normally consolidated fine-grained soil,World applied science journal, 18 (1), 1818-4952.
23. Nakase, A., Kamei, T., and Kusakabe, O. 1988. Constitute parameters estimated by plasticity index, J. Geotech. Engg., ASCE, 114, 844–858.
24. Nath, A. and Dalal, S. S. 2004. The role of plasticity index in predicting compression behavior of clays, Electronic Journal of Geotechnical Engineering, vol. 9, 2004-Bundle E.
25. Nishida, Y. 1956. A brief note on compression index of soils, Journal of SMFE Div., ASCE, 1-14.
26. Ofosu,C.A.B. 2013. Empirical Model for Estimating Compression Index from Physical Properties of Weathered Birimian Phyllites, EJGE, 18, 6135- 6144.
27. Pal, S.K and Ghosh, A 2011. Compaction and hydraulic conductivity characteristic of Indian fly ash, Indian geotechnical conference, December 2011, Kochi, P-773-776.
28. Pal, S.K. and Ghosh, A. 2010. Influence of Physical Properties on Engineering Properties of Class F Fly Ash, Indian geotechnical conference, December 2010, IIT Bombay, 361-364.
29. Ring, G.W., Sallberg, J. R. and Collins, W. H. 1962. Correlation of compaction and classification test data, HRB, 325, 577–587.
30. Saha, S. and Pal, S.K. 2012. Compressibility Behavior of Soil and Fly Ash Used in Successive Layers, EJGE, 17, 2659-2670.
31. Singh, H. P. 2012. Improvement in CBR Value of Soil Reinforced with Jute Geotextile Layers, International Journal of Earth Sciences and Engineering, 5 (2), 1438-1442.
32. Skempton, A.W. 1944. Notes on compressibility of clays. Qtrly. Journal of Geological Society, London, pp 119-135.
33. Sridharan, A. and Nagaraj, H. B. 2000. Coefficient of consolidation and its correlation with index properties of remolded soils, Geotechnical Testing Journal, 27(5).
34. Sudha Rani, Ch. 2013. "Investigation on Engineering Properties of Soil-Mixtures Comprising of Expansive Soils and a Cohesive Non-Swelling Soil, International Journal of Innovations in Engineering and Technology, 2(3), 155-160.
35. Sudha Rani, Ch., Phani Kumar, V. and Togati, N.V.V.K. 2013. Artificial Neural Networks (ANNS) For Prediction *of Engineering Properties of Soils, International Journal of Innovative Technology and Exploring Engineering, 3(1), 123-130.*
36. Sudha Rani Ch. and Phani Kumar, V. 2011. Prediction of Compression Index of Soils Using Artificial Neural Networks (Anns), International Journal of Engineering Research and Applications (IJERA), Vol 1, Issue 4, Pg.no. 1554-1558.
37. Terzaghi, K. and Peck R.B. 1967. Soil mechanics in engineering practice, 2nd edn. Wiley, New York
38. Wang, P., Li, J.S. and Wang, H.F. 2013. Engineering Properties of Heavy Metal Contaminated Soil Affected by EDTA Washing, EJGE, 18, 3909- 3917.