International Journal of Advances in Applied Sciences (IJAAS)
Vol. 2, No. 2, June 2013, pp. 77~84
ISSN: 2252-8814

An Attempt to Relate Consolidation Properties: A Case Study in Baghdad Cohesive Soil

Abbas Jawad Al-Taie[1], Bushra S. Al-Busoda[2]
[1]Ministry of Higher Education and Scientific Research-Office Reconstruction and Projects Department, Iraq
[2]Department of Civil Engineering University of Baghdad, Iraq

Article Info

Article history:

Received Oct 5, 2012
Revised Jan 23, 2013
Accepted Feb 16, 2013

Keyword:

Correlation
Dry unit weights
Natural moisture content
Natural void ratio
Overburden pressure
Overconsolidation ratio
Preconsolidation pressure
Total unit weight

ABSTRACT

The main focus of this study is on the soil properties (preconsolidation pressure (Pc), and overconsolidation ratio (OCR)), that are critical in the determination of the settlement behavior of the structure. Prior knowledge of these properties, even approximate values, will be assets during the planning stages to determine the suitability of structure site. Conducting laboratory tests for the determination of (Pc) will be costly both in terms of time and money. In the present study a specific empirical correlation models are proposed to estimate the (Pc) and (OCR) of undisturbed cohesive soil of Baghdad city using large number of consolidation data. The (Pc) and (OCR) are dependent variables and are treated as functions of natural void ratio (eo), natural moisture content (wo), total unit weight (γt) , dry unit weights (γd), and overburden pressure (Po) which are termed as independent variables. The regression analysis revealed that (eo) and (Po) yielded sufficiently reliable correlation to estimate (Pc). Also, a good estimation was obtained for (OCR) from (Po).

Corresponding Author:

Abbas Jawad Al-Taie,
Lecturer in Ministry of Higher Education and Scientific Research,
Office Reconstruction and Projects Department, Iraq.
Email: abbasjaltaie@yahoo.com

1. INTRODUCTION

The effective preconsolidation pressure (Pc) is the maximum vertical (overburden) pressure experienced by the soil during its geological history, or, it is the largest overburden in which the soil had been consolidated [1],[2]. Most natural soils are preconsolidated to some degree, either by erosion, desiccation, past glacial activity, aging, or other factors. However, soil could be consolidated due to change in the total stress or a change in pore water pressure; both changes would alter the effective stress as stated by Holtz and Kovacs (1981) [3]. The ratio of (Pc) to current effective overburden pressure (Po) is defined as the over consolidation ratio (OCR) and is a convenient term for describing the stress state [2]. Based on (OCR) soils are classified as normally consolidated, over consolidated or under consolidated. In general, for normally consolidated clay, (OCR) ranged from (0.8 to 1.5) and, for overconsolidated clay, (OCR) > 1.5 [4]. (OCR) is used to estimate consolidation in clays), for correlation of strength properties, and for estimating at-rest earth pressure coefficient (Ko) in terms of plasticity index [5],[6],[7]. On the other hand, selection of consolidation parameters such as compression index (Cc) , recompression index (Cr), and coefficient of volume change (mv) is on the basis of (OCR) for computing consolidation settlement [8].

Methods for estimation (Pc) and (OCR) from laboratory test have been presented in literatures. Most of these methods are graphical methods and usually based on the relationship of experimental void ratio and effective consolidation pressure. All these methods, however, are operator dependent as they require accurate reading of logarithmic scale, drafting capability and proper judgment of selecting the points [8].

Casagrande Method, e-log p [9] is the oldest method to evaluate preconsolidation pressure which remains a standard method in comparison to other methods. This method gives good results provided there is a well- defined break point in the e–log p. It is based on the assumption that the soil experiences a change in stiffness, from a stiff response to a soft response, close to the preconsolidation stress. The adjustment of laboratory consolidation test results for soft soil with an attempt to compensate for nominal sample disturbance effect was proposed by Schmertmann (1955) [6] . Janbu (1969) proposed that the consolidation stress could be determined from a plot of the constrained modulus (M = 1/ mv, where mv is the coefficient of volume compressibility) versus the axial stress in linear scale [10]. Janbu (1969) suggested that for clays with high sensitivity and low (OCR), (Pc) might often show up more distinctly in the stress – strain curve plotted using a linear scale [10]. A new method widely used in Brazil depends on an empirical construction from (e–log p) curve was proposed by Pacheco (1970) [11]. It is very fast method and does not require any subjective interpretation results, not scale dependent, and more easy to use in soft soil. Butterfield (1979) is based on the plot of variation between effective stress and volume change of specimen [12]. This method has several variations in the literature such as log (1+e) – log p and ln (1+e) – ln p approach. The preconsolidation pressure is defined as the intersection point of two fitted lines.

Jose, Sridharan, Abraham (1989) suggested a very simple approximate method to evaluate preconsolidation pressure from log e – log p [13]. In this method the point of intersection of two distinct straight lines represents the preconsolidation pressure. This is a direct method and frees from any judgment errors in the location of maximum curvature point.

Senol, Hatipogla, Ozudogru (2005) tried to determine the method which gives less deviation percent from the average values of preconsolidation pressure out of other methods [14]. Consequently, the authors proved that new method (Senol method) gave (16.5%) deviation compared to Casagrande (-41%).

On the other hand, the correlations are also suggested by researchers to obtain (Pc) and (OCR). Nagaraj and Srimivasa (1985) proposed the generalized relationship to predict the (Pc) and (OCR) for saturated uncemented soils. This method gave highest correlation coefficient as compared to other graphical methods in a particular condition [15].

An attempt to establish an empirical relationship between the (OCR) and (e/eL) ratio was carried out by Chetia and Bora (1998) [16]. These authors primarily consider the effects of stress history of the soil, and their characterization and assessment in terms of their overconsolidation ratios (OCR). Also, using soil index and consolidation test data new empirical correlations are derived for (Pc) and (OCR) for alluvial deposits. Numbers of datasets are used for studying (Pc) with soil index and plasticity characteristic [8] .

Finally, it should be mentioned that, there is scarcity in literatures concerning the correlations for (Pc) and (OCR).

2. THE PURPOSE OF THIS STUDY

A laboratory consolidation test takes a considerable amount of time and is both labor- and computation-intensive (unless the test has been automated). In any case it is rather expensive, and in most cases at least two—and preferably three—tests should be performed in each critical stratum. Because of these factors a substantial effort has been undertaken to attempt to correlate the some of the consolidation parameters to some other more easily determined soil index properties. Also, if the first laboratory consolidation test correlates reasonably well with one or more of the available expressions of these parameters, additional verification tests may not be required. Correlations have particular value in preliminary site studies before extensive soil exploration and testing is undertaken for a final design

Bowles (1996) Stated that a reliable estimate of the effective preconsolidation pressure is difficult without performing a consolidation test. He also mentioned that there have been a few correlations given for (Pc). Prior knowledge of (Pc) and (OCR), even approximate values, will be assets during the planning stages to determine the suitability of structure site [17].

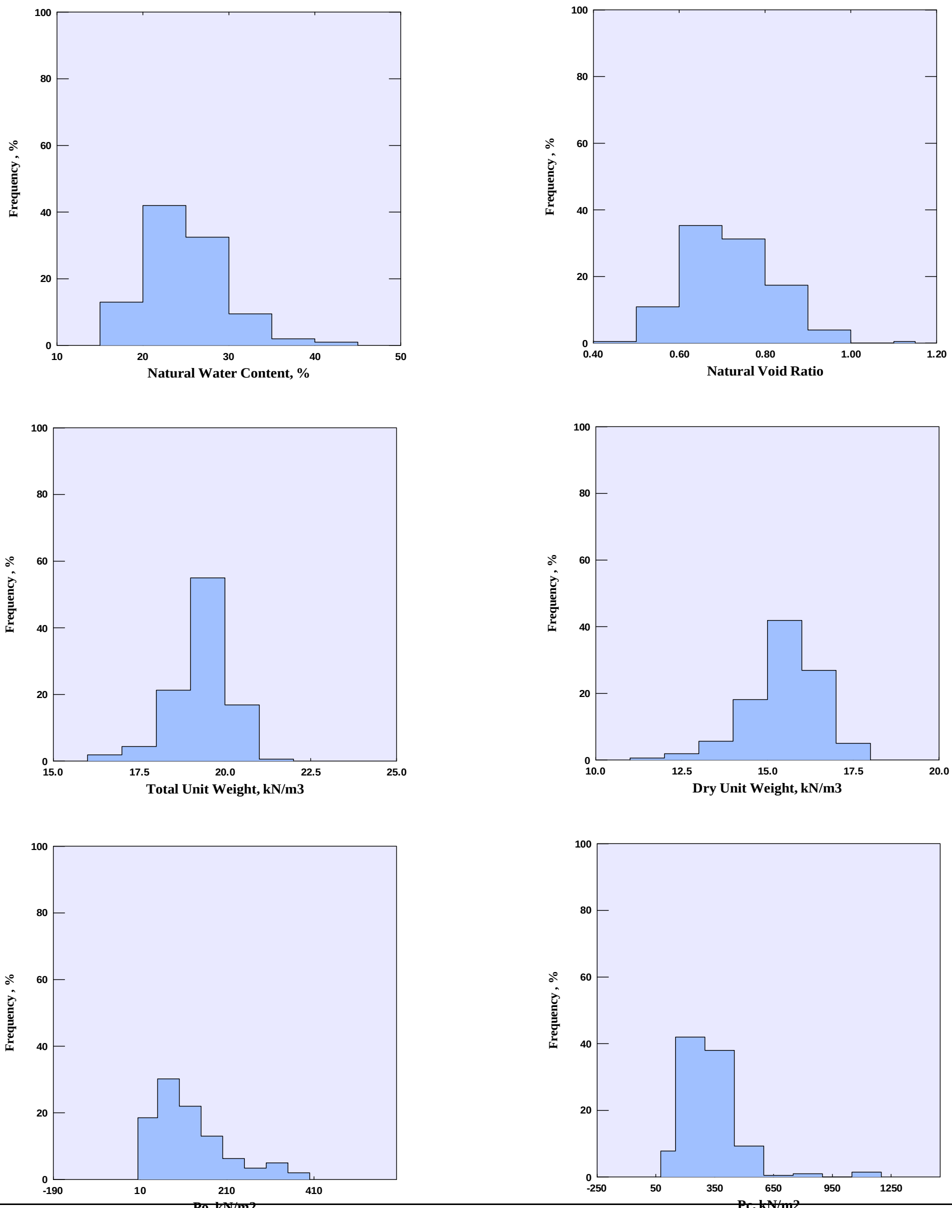
In the present study a specific empirical correlation models are proposed to estimate the (Pc) and (OCR) of undisturbed cohesive soil of Baghdad city using large number of consolidation data. The (Pc) and (OCR) are treated as dependent variables and a functions of natural void ratio (eo), natural moisture content (wo), total unit weight (γt) , dry (γd) unit weights, and overburden pressure (Po).

3. THE DATABASE USED

The data used in this investigation consist of consolidation and physical properties test results obtained during the last years with samples obtained from different parts of Baghdad city. The consolidation tests utilized in this investigation were performed using standard oedometer device. The stress increments followed in all of the tests were the same (25, 50, 100, 200, 400, 800 kPa) and the maximum past overburden (preconsolidation) pressure was determined using the graphical method suggested by Casagrande. The data sets used in the analysis consisted of seven soil parameters obtained from various tests. The statistical parameters were calculated for the whole database as given in Table 1. The frequency histograms for each soil parameter are shown in Figure 1. As can be observed from the frequency histograms and from the statistical parameters given in Table 1, for most of the soil parameters it appears realistic to assume a normal distribution.

Table 1. Summary of Statistical Parameters for all Soil Properties of all Samples

Soil Properties	wo	Eo	γt	γd	Po	Pc	OCR
Units	%	-	kN/m3	kN/m3	kPa	kPa	-
Number of Data	200	204	160	160	205	204	204
Mean	25.2	0.719	19.37	15.47	125.53	326.12	3.74
Median	24.79	0.710	19.50	15.59	102	302.5	3.11
Std. Deviation	4.71	0.11	0.77	1.06	86.22	157.08	2.79
Variance	22.151	0.011	0.597	1.117	7433	24673	7.763
Minimum	15	0.497	16.20	11.33	9.30	82	0.91
Maximum	43	1.12	21.10	17.69	384	1150	19.29



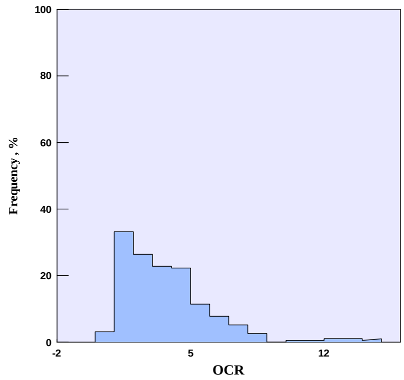


Figure 1. Frequency Histograms for Soil Properties

4. PREDICTION OF (PC) AND (OCR)

The main purpose of this study was to determine the most suitable correlation for evaluating the (Pc) and (OCR) in terms of physical soil properties and (Po) based on the database. The first step was the calculation of correlation coefficient matrices for the whole data. A correlation coefficient (R) with values greater than or equal (± 0.5) was adopted for developing various regression models. The correlation coefficients calculated between the (Pc) and (OCR) and the other soil parameters and the resulting equations for all cases adopted in this study are shown in Table 2 and Figures (2 to 5).

Table 2. Correlation Coefficients between (Pc) and (OCR) and Other Soil Parameters

Independent Variables	Correlation Coefficient (R)					
	Linear Regression		Curve Estimation			
	P_c	OCR	P_c	Model	OCR	Model
w_o	0.036	0.299	0.042	2nd polynomial	0.387	Exponential
e_o	0.035	0.295	0.093	2nd polynomial	0.386	Power
γ_t	0.036	0.219	0.040	2nd polynomial	0.362	Power
γ_d	0.014	0.287	0.070	2nd polynomial	0.428	Power
P_o	0.412	0.599	0.538	Power	0.817	Power
w_o/P_o	0.369	0.783	0.546	Power	0.789	2nd polynomial
e_o/P_o	0.370	0.806	0.555	Power	0.820	2nd polynomial
γ_t/P_o	0.362	0.810	0.516	Power	0.814	2nd polynomial
γ_d/P_o	0.329	0.750	0.404	Exponential	0.750	2nd polynomial

As can be observed in this table, the total unit weight and dry unit weight have a low correlation coefficient value for all cases considered in evaluating the (Pc) and (OCR). The highest correlation coefficients for the (Pc) and (OCR) were obtained with relation to overburden pressure (Po). The correlation coefficients given in this study were determined on the basis of linear regression models. Also, in order to improve the calculated correlations, curve estimation using models shown in Table 2 were performed and the related correlation coefficients were calculated. It was observed that, in most cases, significant increase in the value of the correlation coefficient was obtain when the curve estimation used in the regression analysis. Re-examination of Table 2 and Figures (2 to 5) reveals that addition of other independent variables to the overburden pressure in the estimation of (Pc) and (OCR) has significant contribution to the magnitude of (R).

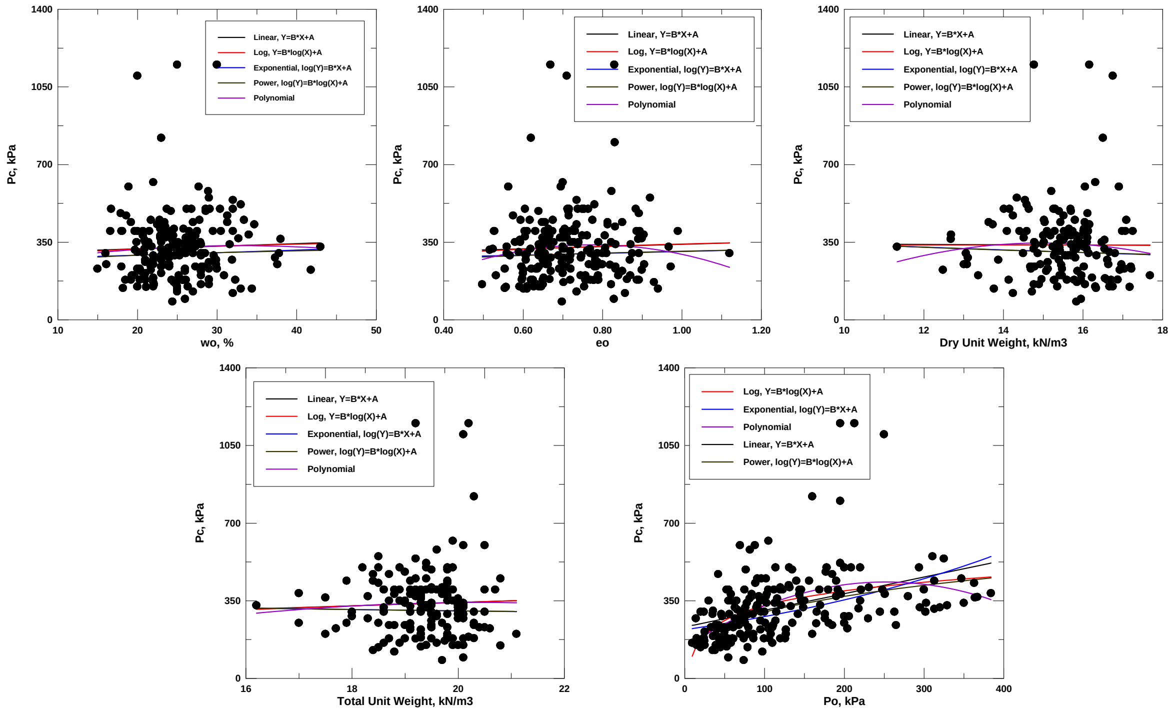


Figure 2. Correlation of (Pc) with Physical Soil Properties and (Po)

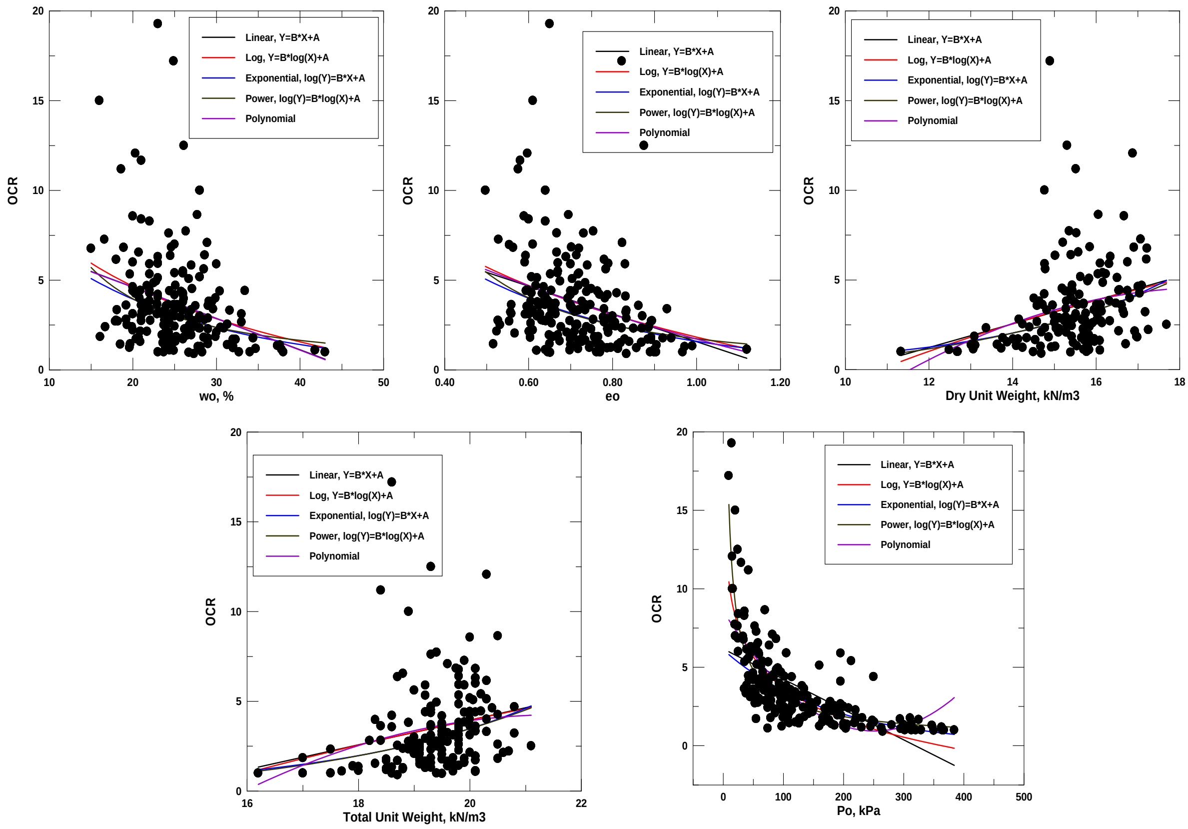


Figure 3. Correlation of (OCR) with Physical Soil Properties and (Po)

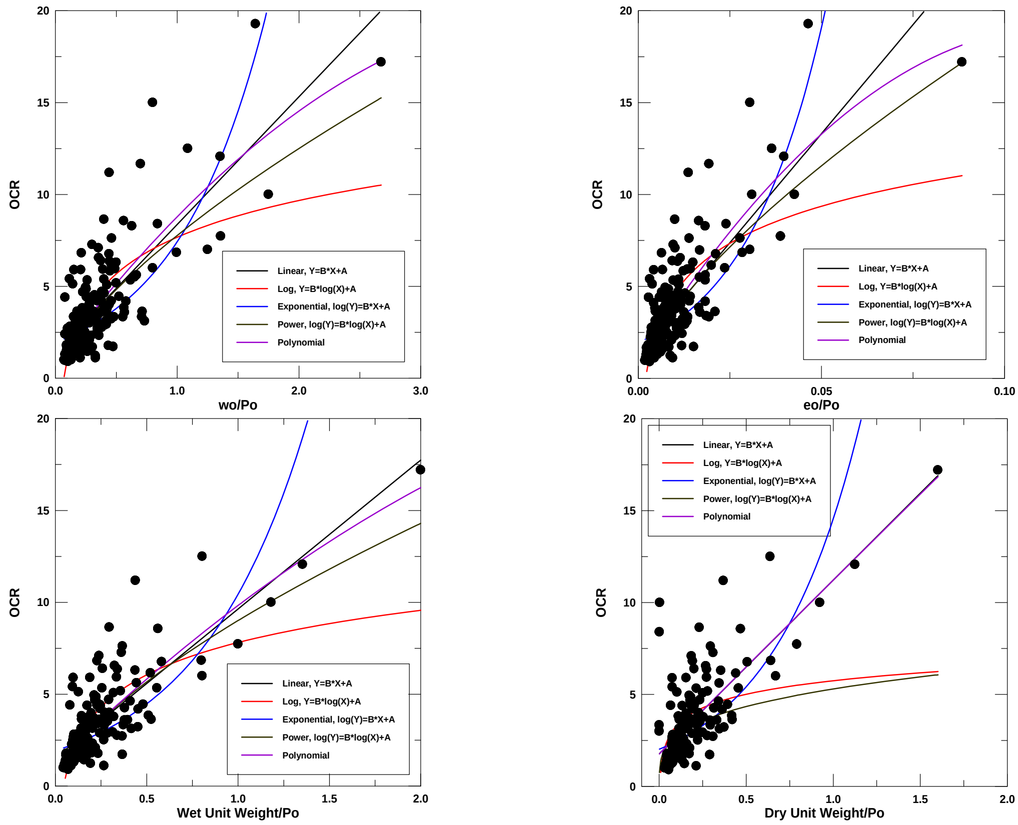


Figure 4. Correlation of (Pc) with the Ratio of Physical Soil Properties to (Po)

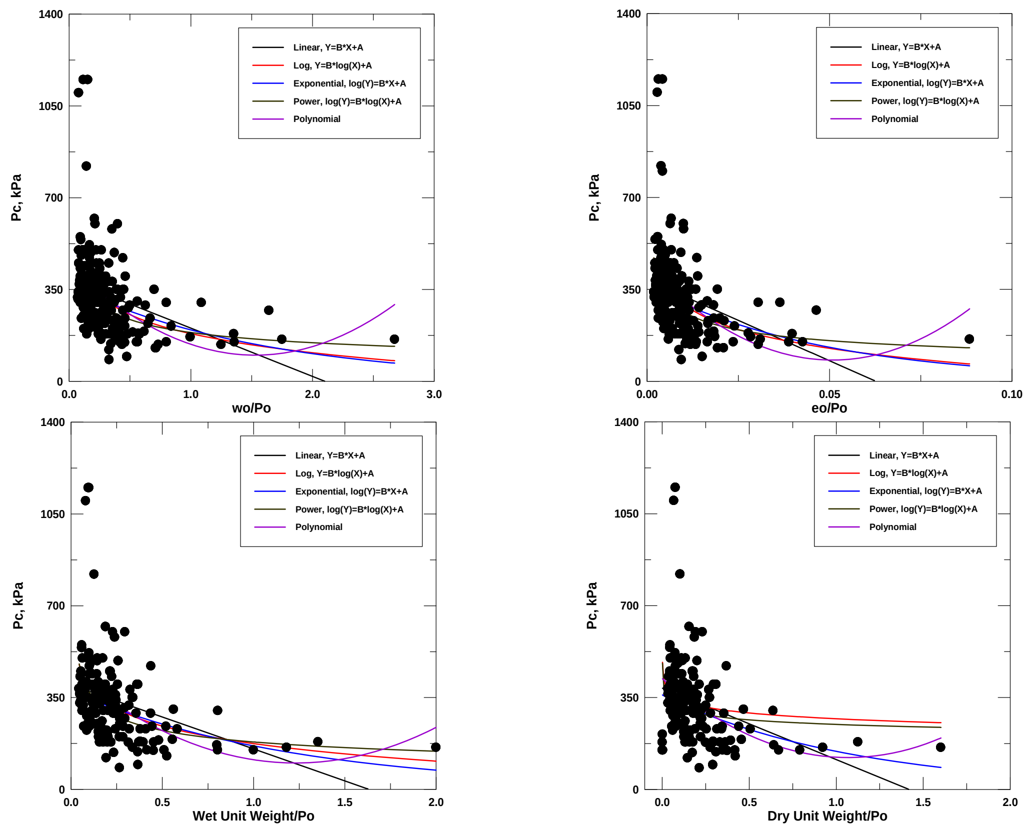


Figure 5. Correlation of (OCR) with the Ratio of Physical Soil Properties to (Po)

A list of possible relationships for estimating the (Pc) and (OCR) using various index parameters developed in this study is summarized in Table 3. During this study, all possible relationships were tried; however, naturally in some of these relationships the correlation coefficients was low. The equations given in Table 3 are the ones which had the highest correlation coefficient (R≥ ± 0.5).

Table 3. Summary of Relationships Developed to Evaluate (Pc) and (OCR)

Independent Variables	Correlation Coefficient (R)	Regression Equation
Relationships Developed to Evaluate (Pc)		
P_o	0.5363	$P_c = 71.64 (P_o)^{0.3099}$
w_o/ P_o	0.5456	$P_c = 186.1 (w_o/P_o)^{-0.3392}$
e_o/ P_o	0.5558	$P_c = 56.23 (e_o/P_o)^{-0.3377}$
γ_t/ P_o	0.5157	$P_c = 180.6 (\gamma_t/ P_o)^{0.3122}$
Relationships Developed to Evaluate (OCR)		
P_o	0.5916	$OCR = 6.167 – 0.0193 P_o$
P_o	0.8166	$OCR = 71.64 (P_o)^{-0.69}$
w_o/ P_o	0.7828	$OCR = 1.417 + 6.949 (w_o/ P_o)$
w_o/ P_o	0.7889	$OCR = 1.024 + 8.767 (w_o/ P_o) – 1.005 (w_o/ P_o)^2$
e_o/ P_o	0.8077	$OCR = 1.449 + 237.2 (e_o/ P_o)$
e_o/ P_o	0.8126	$OCR = 0.947 + 314.8 (e_o/ P_o) – 1362 (e_o/ P_o)^2$
γ_t/ P_o	0.8105	$OCR = 1.529 + 8.107 (\gamma_t/ P_o)$
γ_t/ P_o	0.8136	$OCR = 1.29 + 9.573 (\gamma_t/ P_o) – 1.058 (\gamma_t/ P_o)^2$
γ_d/ P_o	0.7503	$OCR = 1.761 + 9.457 (\gamma_d/ P_o)$
γ_d/ P_o	0.7503	$OCR = 1.752 + 9.532 (\gamma_d/ P_o) – 0.0612 (\gamma_d/ P_o)^2$

Finally, it appears from the study conducted that natural void ratio (eo) and effective overburden pressure (Po) yielded sufficiently reliable correlation to estimate preconsolidation pressure (Pc). Also, a good estimation was obtained for overconsolidation ratio (OCR) from effective overburden pressure (Po).

5. CONCLUSION

A database consisting of large numbers of data sets containing consolidation and physical properties test results obtained during the last years from different parts of Baghdad city was used to conduct a statistical study to determine suitable correlations for estimating preconsolidation pressure (Pc) and overconsolidation ratio (OCR). For this purpose, various regression models were adopted and a parametric study was carried out in order to obtain the most suitable and practically applicable relationships. It was observed that the natural void ratio (eo) and effective overburden pressure (Po) yielded sufficiently reliable correlation to estimate preconsolidation pressure (Pc). Also, a good estimation was obtained for (OCR) from (Po).

ABBREVIATION

Symbol	Description
e	void ratio
e_L	void ratio at liquid limit
e_o	natural void ratio
m_v	coefficient of volume compressibility
OCR	overconsolidation ratio
p	consolidation pressure
P_c	preconsolidation pressure
P_o	effective overburden pressure
R	Correlation Coefficient
w_o	natural moisture content
γd	dry unit weights
γt	total unit weight

REFERENCES

[1] Casagrande, A. "The Determination of the Preconsolidation Load and Its Practical Significance", *1st ICSMFE*, Vol. 3. Pp. 60-64, 1936.
[2] Kulhawy F. H. and P. W. Mayne. "Manual on Estimating Soil Properties for Foundation Design", Rpt. EL-6800, *Electric Power Research Inst.*, Palo Alto, 1990.
[3] Holtz, R. D., and W. D. Kovacs. *An Introduction to Geotechnical Engineering*, Prentice-Hall, Englewood Cliffs, NJ, 1981.

[4] Clemence, S. P. and Finbarr, A.O. "Design Considerations and Evaluation Methods for Collapsible Soils", *Proceedings of ASCE*. Pp. 80–116, 1879.
[5] Brooker, E.W. and Ireland, H.O. "Earth Pressures at Rest Related to Stress History", *Can. Geotech. J.*, II, 1965.
[6] Schmertmann, J. H. "The Undisturbed Consolidation Behavior of Clay", *Trans. ASCE*, Vol. 120. Pp. 1201-1233, 1955.
[7] Terzaghi, K. and Peck, R. B. *Soil Mechanics in Engineering Practice*, 2nd ed., Wiley, New York, 1967.
[8] Solanki, C. H. and Desai. M. E. "Preconsolidation Pressure from Soil Index and Plasticity Properties", *The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG)* Goa, India. Pp. 1475-1479, 2008.
[9] Schmertmann, J. H. "Static Cone to Compute Static Settlement over Sand", Proc. ASCE, *J. Soil Mech. Found. Eng. Div.*, Vol. 96 Pp. 1011–1043, 1970.
[10] Janbu, N. "The Resistance Concept Applied to Deformations of Soils", *Proc. 7th Int. Conf. Soil Mech. Found. Engng, Mexico*, Vol. 1. Pp. 191-196, 1969.
[11] Pacheco Silva, F. "A New Graphical Construction for Determination of the Pre-Consolidation Stress of a Soil Sample", *In Proceedings of the 4th Brazilian Conference on Soil Mechanics and Foundation Engineering, Rio de Janeiro, Brazil*, Vol/Issue: 2(1). Pp. 225–232, 1970.
[12] Butterfield, R. "A Natural Compression Law for Soils (an Advance on e-log p)", *Geotechnique*, Vol/Issue: 29(4). Pp. 469-480, 1979.
[13] Jose, B. T., Sridharan, A. and Abraham, B. M. "Log-Log Method for Determination of Preconsolidation Pressure", *GTJ, ASTM*, Vol/Issue: 12(3). Pp. 230-237, 1989.
[14] Senol, A., Hatipogla, M. and Ozudogru, T. Y. "The Calculation of Preconsolidation Pressure Result of Various 'CL' Subgrades", *Proceedings of International conference on Problematic soils Geoprobe Cyprus*, 2005.
[15] Nagaraj, T. S., and B. R. Srinivasa Murthy. "Prediction of the Preconsolidation Pressure and Recompression Index of Soils", *GTJODJ*, Vol/Issue: 8(4). Pp. 199-202, 1985.
[16] Chetia, M, Bora, P. K. "Estimation of Over Consolidated Ratio of Saturated Uncemented Clays from Simple Parameters", *Indian Geotechnical Journal*, Vol/Issue: 28(2) Pp. 177 – 194, 1998.
[17] Bowles, J. E. *Foundation Analysis and Design*, 5th edition Mc Graw-Hill Book Company Inc. New York, 1996.

BIOGRAPHY OF AUTHOR

Mr Abbas Jawad Al-Taie His obtained graduated BSc in Civil Engineering, University of Baghdad, IRAQ (1st Class Honours). The M.Sc. degree in soil mechanics and foundation engineering branch, university of Baghdad, college of engineering, Iraq (Graduated with Honours) in the year 2002 with specialization in Soil Mechanics, Foundation Engineering, Geotechnical and Structural Design of Pile Foundation, Geotechnical and Structural Design of Shoring, Geotechnical Investigation, Classic and Advanced Laboratory Soil Testing , Rock Mechanics, Classic and Advanced Field Testing for Geotechnical and Geophysical Purposes, construction of Foundation for different Building Types. Currently He was Assistant Lecturer in Ministry of Higher Education and Scientific Research- Office Reconstruction and Projects Department, IRAQ; He has many papers published in various National Journals in Iraq.