Empirical Models for the Determination of the Compression Index from the Limits of Atterberg: Case of the soils of the Issaba depression in Benin

ABSTRACT

The good realization of any infrastructure in civil engineering requires the implementation of geotechnical investigations. During these investigations, the physical properties of the soil, especially the mechanical ones, must be determined with care and precision because of their capital importance in the preliminary studies before the realization of the work. The soil compression index is one of these mechanical parameters, which is determined by laboratory tests. It allows the calculation of settlements and is therefore essential especially for fine clay or silty soils which are often subject to swelling phenomena. However, the realization of the test to find the compression index in laboratory takes time, and the test itself proves delicate. Several authors have therefore proposed the determination of this index from the limits of Atterberg, which can be obtained more quickly and easily. Through this study, empirical models have been proposed to easily calculate the compression index. Regression analyses in Matlab with 2D and 3D graph systems were performed for this purpose. The model was established for the soils of the Issaba depression in the Republic of Benin, where clayey and silty soils are very swelling. The models obtained show very good correlations with R^2 coefficients higher than 0.80 and the RMSE error minimized to less than 0.5.

Keywords : empirical model ; correlation ; regression ; compression index ; Atterberg limits ; Issaba depression

1-INTRODUCTION

A sustainable realization of any infrastructure requires the implementation of geotechnical investigations. During these investigations, the physical properties of the soil, especially the mechanical properties, must be determined with care and precision because of their crucial importance in the preliminary studies for the realization of the work. The soil compression index is one of these mechanical parameters, which is determined by oedometer tests. It allows the calculation of settlements and is therefore essential especially for fine clay or silty soils which are often subject to instability phenomena. However, it takes time to carry out the laboratory test to find the compression index, and the test itself is delicate. Several authors have proposed various methods for the determination of this index from the Atterberg limits result, which can be obtained more quickly and easily.

Correlations and empirical relationships are used extensively in geotechnical engineering. The use of correlations and empirical relationships provides a fast, cost-effective means of predicting the value of a parameter based on the values of some other, possibly more easily determined, parameters provided that the appropriate correlations are employed. Generally, the more easily obtained parameters are correlated to the parameters of more difficult and complex test procedures. The correlation between two or more soil properties has been found to be dependent in varying degrees on soil type, the testing method used to obtain the numerical value of the parameter itself and the homogeneity of the soil [3]. Many correlations between soil properties have been published. In the last decade, many researches were performed to correlate the physical properties with the mechanical properties [1].

Knowledge of the consolidation properties of a soil is important in geotechnical design, particularly as they related to settlement of structures. These properties are usually determined by oedometer testing, and determined in terms of the compression index Cc and recompression index Cs. Compression index (Cc) is one of the salient parameters which the geotechnical engineer seeks to unravel to establish the safety of the proposed structure immediately after construction and during the life time of the structure [4].

Compression index value is required by the geotechnical to determine the soft clay soil settlement. [5]. The Cc is an important one-dimensional compressibility parameter with particular relevance to primary settlement calculations for normally consolidated or lightly overconsolidated natural soils [6].

However, the value of Cc testing in the laboratory is time consuming and the cost of laboratory testing is relatively expensive compared to other soil characteristics testing. For comparison, the calculation of unit weight and void ratio can be completed within 1-2 day, while the calculation of the Compression index with one-dimensional consolidation test in laboratory is completed in more than 1 week [5]. The cost of consolidation testing is relatively high compared to other common engineering tests and may be considered cost prohibitive for very small projects. Hence it is cost effective to develop correlations between consolidation properties and other easily obtained properties, like the index properties. In view of the cost implications of the consolidation test, investigators have correlated the consolidation properties of soils and other easily and cheaply obtained properties, like the index properties [7]. Whereas planners and engineers usually needed that data quickly, so the use of the empirical formula is preferred [5].

Index properties of soil such as Atterberg Limits, moisture content and initial void ratio are basic properties of soils. Therefore, it is possible to use these index properties to predict the compression index of the soil. Empirical models relating various index properties to the compression index have been presented by many researchers [4]. The oldest correlation models were established by Skempton (1944) [8] for Remoulded clays, Nishida (1956) [9] and Yamagutshi (1959) [10] for Various clay, Peck and Reed (1954) [11] for Chicago clays , Hough (1957) [12] and Moran et al. (1958) [13] for Organic soils, Cozzolino (1961) [14] for Brazilian clays, Terzaghi and Peck (1967) [15] for Normally consolidated clays. We can also mention Sowers (1970) [16] for Soils with low plasticity, Azzouz et al (1976) [17] for Various clay, Wroth and Wood (1978) [18], Bowles (1979) for Organic silt and clays [19], Al-Khafaji and Andersland (1992) [20], Hong and Onitsuka (1998) [21] and many others.

Many researchers have used linear regression to establish empirical models between soil parameters. We can mention Yoon et al. (2004) [22] who proposed regression models for predicting compression index for marine clay, Abbasi et al (2012) [23] used regression analysis to predict the compression behavior of normally consolidated fine grained soil, and Nihad (2020) [1] who ajusted the equations of Rashed et al (2017) [24]. In addition, Yildirim and Gunaydin (2011) [25] concluded that, the correlation equations obtained as a result of regression analyses are in satisfactory agreement with the test results and recommended that the proposed correlations will be useful for a preliminary design stage of a project where there is a financial constraint and limited time. It is evident in literature that prediction of compression index with regression analysis has proved to be successful and widely accepted [4].

Correlations are widely referenced by geotechnical designers, although strictly they should not be applied to soils elsewhere without considering the soil origin and sampling method [17]. In the south of Benin, a median depression called Lama depression, subdivides the bar land plateaus into two groups [26]. In this depression is found clay soils with high swelling potential, which generate various disorders in the infrastructure as mentioned (Gbaguidi et al, 2011) [27] and (Tankpinou kiki, 2004) [28]. In addition, (Agbelele et al, 2016) [28] showed that east of this depression, the soils are composed of silt and clays of illite and montmorillonite type. Their swelling potential and pathological risk were found to be high [29]. Therefore, this current study presents empirical models involving the compression index and Atterberg limits of soils in the Issaba depression, using linear regression analysis. The models established in this study can be used to predict the compressive index for preliminary design purposes and also to verify the accuracy of consolidation tests in this depression.

2. MATERIALS AND METHODS

2.1 DESCRIPTION OF STUDY AREA

The Republic of Benin extends perpendicularly to the coastline of the Gulf of Benin between the meridians 1° and 4° and the parallels 6° and 12° north. Narrowly constricted south of the 9th parallel by Togo and Nigeria (average width 120 km), it extends further north to the borders of Burkina Faso and Niger.

The Median Depression is the great depression crossing southern Benin from west to east in a southwest-northeast direction. This depression leaves Nigeria, crosses Benin and continues into Togo according to (Mondjannagni, 1977) cited by (Agbelele, 2017) [26]. The median depression is oriented generally from west to east and forms a vast furrow 130 km long and varying in width from 5 km (Tchi) to 25km (Issaba). It is called Issaba depression in the east, Ko depression in the center and Tchi depression in the west. It constitutes a low region with an altitude of less than 50 m, with clay soil [28].

2.2 SAMPLING AND QUALITY ANALYSIS

The data used for the study consist of laboratory results of soils sampled during geotechnical investigations in the localities of Massè, Onigbolo, Avissa, Ita-Itèlè, Issaba, Illèmon, Kounotcho, Adogon, and Kpoulou of the depression depths variants from 0 to 3 m. The parameters such as the compression index, the liquidity limit, the plasticity index (PI), the plasticity limit (PL) have been determined to identify and characterize the nature of the soils of each site. In their 2016 study on the physico-mechanical characterization of clay soils and the Issaba depression in southeastern Benin published in the article Afrique Science, vol 12 n°2, Agbelele et al showed that the soils of Adogon, Kpoulou, Onigbolo, Issaba and Illèmon are very plastic clays of class A-7-5 (according to my AASHTO classification) ; and in the other localities, clays of class A-7-6. Silt is also found in the Kpoulou, Issaba and Illèmon areas.

Data presented in Table 1 were used for the present study to determine the modulus of compression by an empirical model from the parameters of the Atterberg limit in the same area.

The compression index values are taken from table 1 [28] and the liquid limit and plasticity limit values are taken from table 3 [28]. The liquid limit is obtained through the difference between the liquid limit and the plasticity index.

From this results the table 1 below used in the context of this presentwork.

Table 1 Results of the tests used

Sites	Deepht (m)	Compression index (Cc)	Liquidity limit LL	Plasticity index PI	Plasticity limit PL
lllemon	0,00-0,40	0,82	70	43	27
	0,40-1,00	0,352	86	57	29
	1,00-2,00	0,359	86	46	40
	2,00-3,00	0,357	91	48	43
lssaba	0,00-0,40	0,345	110	75	35
	0,40-1,00	0,355	92	37	55
	1,00-2,00	0,327	79	49	30
	2,00-3,00	0,34	89	31	58
Onigbolo	0,00-0,40	0,56	75	41	34
	0,40-1,00	0,49	68	39	29
	1,00-2,00	0,59	77	45	32
	2,00-3,00	0,48	70	40	30
Kpoulou	0,00-0,40	0,375	74	39	35
	0,40-1,00	0,358	107	40	67
	1,00-2,00	0,363	95	45	50
	2,00-3,00	0,416	55	31	24
lta-ltèlè	0,00-0,40	0,28	80	61	19
	0,40-1,00	0,27	91	63,2	28
	1,00 -2,00	0,25	93	56	37
	2,00-3,00	0,27	84	55	29
Massè	0,00-0,40	0,29	88	62	26
	0,40-1,00	0,28	92	65	27
	1,00-2,00	0,26	86	62	24
	2,00-3,00	0,28	95	65	30
Adogon	0,00 -0,40	0,31	46,4	26,3	20
	0,40-1,00	0,29	50	27	23
	1,00-2,00	0,33	45	26,8	18
	2,00-3,00	0,35	50	25	25
Avissa	0,00-0,40	0,28	91	60	31
	0, 40-1, 00	0,285	92,7	62	31
	1,00 -2,00	0,3	89,78	63	27

	2,00-3,00	0,297	92	62	30
Kounotcho	0,00-0,40	0,27	69	46	23
	0,40-1,00	0,31	75	48	27
	1,00-2,00	0,32	79	50	29
	2,00-3,00	0,29	70	44	26

2.3 ANALYTICAL METHODS

Linear regression was used to establish correlation models between the compression index and the parameters of the Atterberg limit such as: the compression index, the liquidity limit, the plasticity index

Linear Regression is a statistical tool for the investigation of relationships between dependent variable and independent variables. The dependent variables are used to predict the independent variables; the aim of linear regression is to find the value of intercept and slope of the line that best predicts independent variables from dependent variables. The form of the regression equation is commonly written as [4]:

$$Y = MX + C$$

where Y is the independent variable, X is the dependent variable; M and C are the slope and intercept of the regression equation respectively. The regression procedure finds estimates of the C and M by a minimization process. This minimization is done by minimizing the sum of squares of the vertical distances between the data points and the best-fit line in X-Y space. [28].

The predictive performance is judged by the coefficient of determination, R^2. For example an R^2 value of 0.5 means that 50 percent of the variation in Y is being explained by the X variable. R^2 values vary between 0.0 and 1.0. An R^2 value of 0.0 means that the X variable has no predictive advantage (i.e., there is no correlation between X and Y. An R^2 value of 1.0 means that the X variable is a perfect predictor of Y, with no variation (i.e., there is a perfect correlation between X and Y) [28]. The validity of correlations was also assessed on the basis of root mean square error (RMSE). RMSE is the square root of the average the squared difference between the values calculated using a correlation and the corresponding observed values determined from laboratory tests. Errors in RMSE are squared before they are averaged; consequently, relatively high weight is given to large errors. This means the RMSE is most useful when large errors are particularly undesirable [7]. The RMSE has been used many researchers to evaluate the performance of empirical equations like Park and Lee (2011) [29], Ahadiyan et al (2008) [30], Ozer et al (2008) [30], and many others .

To conduct the regression analysis, Matlab R2020a software was used using 2D graph systems for the relationships between Cc and respectively LL, PL, PI. A 3D graph system was then used to find the relationship between the three soil properties. The least squares method was used as well as the degree 1 polynomial model for each of the variables. The 3D trend was center and scale.

3 RESULTS AND DISCUSSIONS

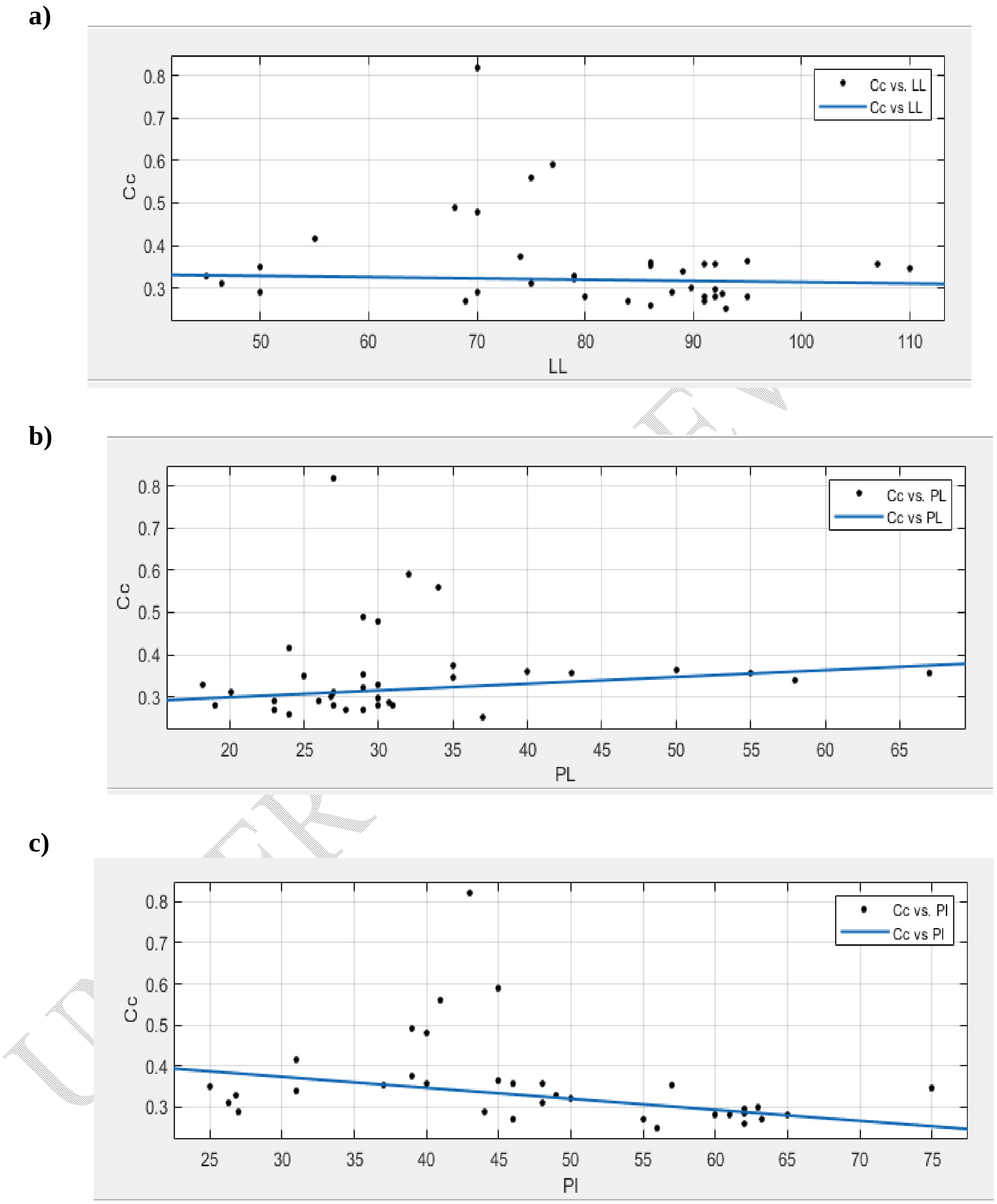

Fig. 1 Trend curves for the linear models of the the compression index against , **a** Liquidity limit, **b** Plasticity limit, **c** Plasticity index

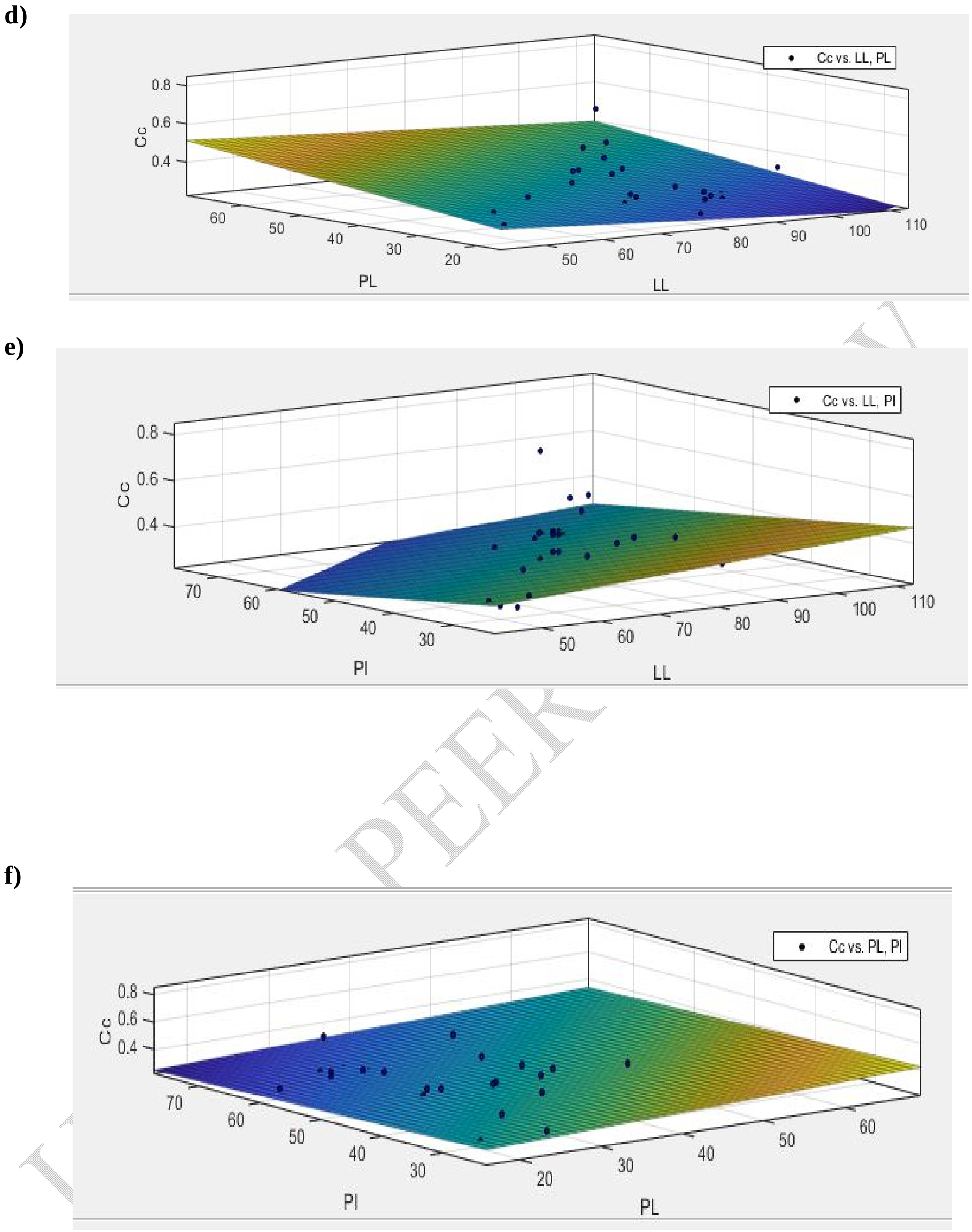

Fig. 2 Trend curves 3D for the polynomial models of degree 1 , **d** Determination Cc via LL and PL, **e** Determination Cc via LL and PI, **f** Determination Cc via PL and PI

Table 2 Summary of Regression Analyses

Independent Variable	Empirical Model	R^2	R^2 adjusted	RMSE
Plastic Limit – PL	Cc = -0,001607 PL + 0,2666	0,9006	0,8976	0,03614
Plasticity Index – PI	Cc = -0,002678 PI + 0,4541	0,9103	0,9076	0,03433
Liquid Limit - LL	Cc = -0,0002941 LL+0,3432	0,9045	0,9017	0,03542
LL and PL	Cc = 0,3228 - 0,02674 LL - 0,03595 PL	0,8209	0,81	0,04924
PL and PI	Cc = 0,3228 + 0,01798 PL - 0,02192 PI	0,8209	0,81	0,04924
LL and PI	Cc = 0,3228 + 0,02674 LL - 0,04384 PI	0,8209	0,81	0,04924

The graphs indicated that there is a significant level of correlation between the compression index and the other parameters. The points are well distributed around the regression line or plane. The coefficient of determination R^2 is close to 1 (greater than 0.8) and confirms the existence of a high correlation between the variables. The coefficient equal to 0.8209 for the 3D analysis means that about 82.09% of the variables LL, PL and PI can be predicted by Cc, and about 90% in 2D analysis. As for the RMSE error, it has been minimized to a value lower than 0.5. The values of R^2, adjusted R^2 and RMSE are identical for the 3D analyses, as well as the constant value of the relation which is equal to 0.3228.

4 CONCLUSION

The results show the possibility of reliabe prediction of the compressive index of clayey soils based on Atterberg Limit data. This proved to be useful and practical method for the preliminary design stage due to the fact that the standard odometer testing is relatively expensive and time consuming. However, the empirical model should be carefully used without negligence of required standard testing.

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