Research Article

Aydın Alptekin* and Hidayet Taga

Prediction of Compression and Swelling Index Parameters of Quaternary Sediments from Index Tests at Mersin District

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Abstract: Compression and swelling index parameters, obtained from consolidation test, are used to calculate settlement for normally and over-consolidated soils respectively. When the conditions are not suitable to perform that test, various alternative methods are investigated to get those parameters without carrying out the consolidation test. In this study, a data set including 18 marine and 40 terrestrial undisturbed Quaternary sediments was taken from southern parts of Mersin City, Turkey. Parameters obtained from consolidation test and index tests were correlated by applying simple and multiple regression analyses. The initial void ratio is the main determiner for estimating both the compression and swelling index parameters. Although attempts have been made to correlate parameters with wide distribution of samples, there is no study done with narrow range. The database was divided to subgroups according to the Plasticity chart to obtain more reliable equations. To test the significance of regression analyses, T and F-tests were done. With this study, statistically significant new equations with very high correlation coefficients are proposed.

Keywords: Compression index, Swelling index, Index tests, Quaternary sediments, Plasticity chart, Regression analyses, Significance tests

1 Introduction

Mersin, a coastal town located at the south of Turkey, has suitable opportunities to become the main gate of trade at Mediterranean Sea (Figure 1). Mersin City has the characteristic properties of Mediterranean climate. The population of Mersin increases day by day, as a result dense housing is seen at the whole city especially along the coastline. To prepare a better master plan to the city, the properties of the soil, especially the ones obtained from consolidation test should be known properly. Antalya, nearly the same geological and environmental properties of Mersin, have been suffering from foundation settlement problems [1].

Compression index (Cc) and swelling index (Cs) parameters (Figure 2), used for settlement calculation, can be obtained from one-dimensional consolidation test [2]. Sometimes performing that test may not be possible due to three main reasons. Firstly, consolidation test takes nearly 10 days, 7 days for compression and the other 3 days are for swelling. Secondly, to perform that test, undisturbed fine-grained soil sample is needed. Thirdly, the testing equipment is expensive so it may not be possible that every laboratory has one oedometer device. Moreover, even if all these conditions are suitable, it is not an easy task to take undisturbed sample from field and perform consolidation test without disturbing the soil in the laboratory. Therefore, new ways are searched to get the Cc and Cs parameters.

Index tests are short-term tests that could be done to disturbed and undisturbed samples. Moreover, the equipment used for index tests are much more economical than mechanical tests. In this study, proposing statistically significant new equations with high correlation coefficients (r) between parameters obtained from consolidation test and index tests is aimed.

Many researchers [3–29] suggested equations between Cc, Cs and index properties of soils. Researches have been made by using either marine or terrestrial samples to predict compression and swelling index. Some previous studies [3, 6, 10, 11, 15, 20, 22–24, 29] used remoulded samples, while [4, 5, 7, 8, 13, 14, 16, 18, 21, 25, 27] have used undisturbed samples. Until this present, there has not been any study carried out with subgroups. Index properties such as the Atterberg limits (Table 1), natural water content (Table 2) and initial void ratio (Table 3) were used by many researchers to forecast the compressibility properties of soils. [9, 16, 28] have used multiple regression analysis, the r value increased a bit (Table 4). To predict Cs parameter, very few studies [18, 19, 27] were done (Table 5). [7, 14] have

***Corresponding Author: Aydın Alptekin:** Mersin University Mersin, Turkey; Email: aydinalptekin@mersin.edu.tr
Hidayet Taga: Mersin University Mersin, Turkey

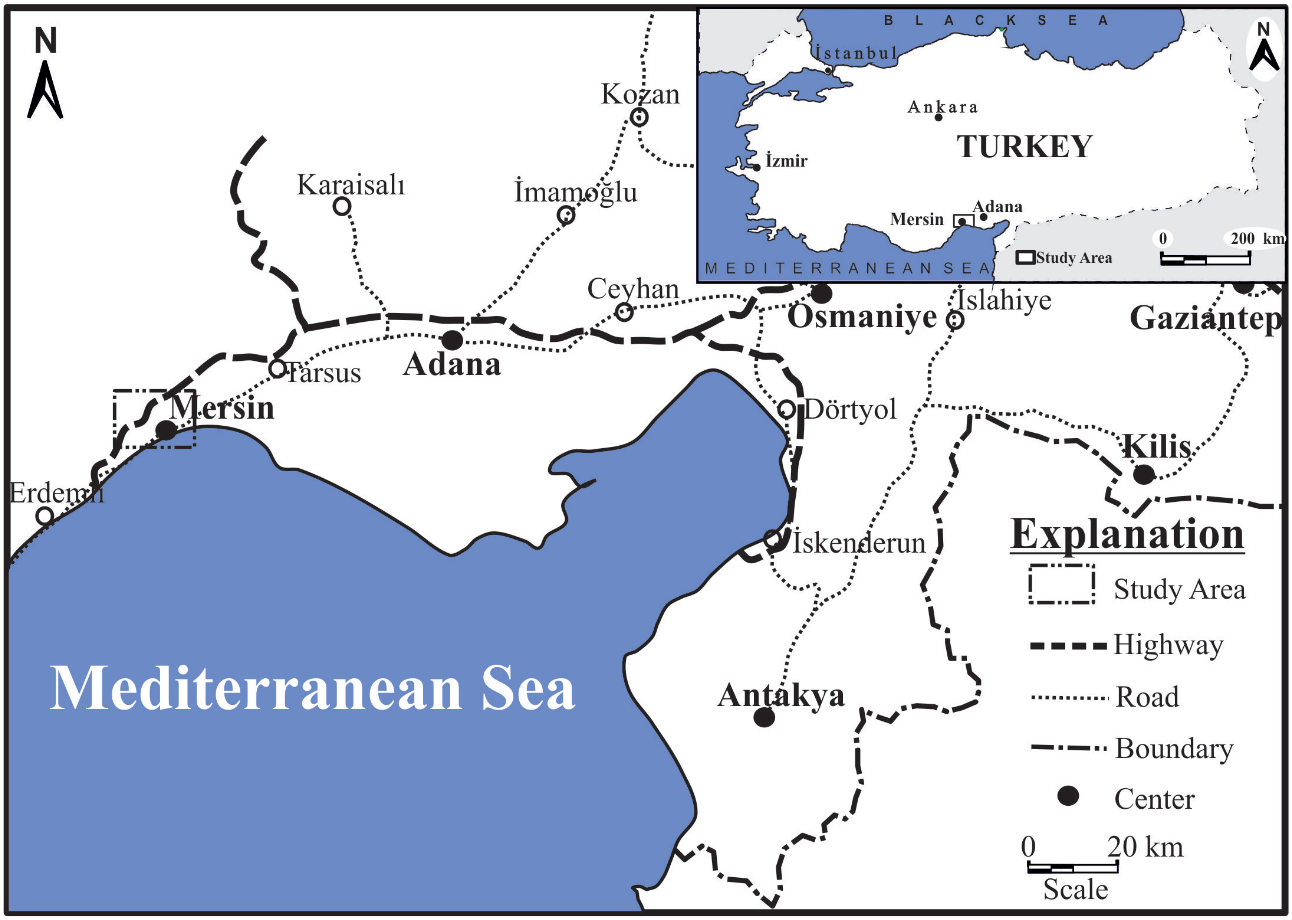

Figure 1: Location map of the study area

Table 1: Previously suggested equations between Atterberg Limits and Cc

Equation	r	N	Type of soil	Reference
Cc=(0.0076*LL)-0.087	0.975	25	Remoulded	3
Cc=0.006*(LL-9)	0.59	678	Undisturbed	4
Cc=0.0063*(LL-10)	-	-	Undisturbed	8
Cc=-0.390+ (0.332*log(LL))	0.961	20	Remoulded	10
Cc=0.014*(PI+3.6)	0.910	10	Remoulded	11
Cc=0.006*(LL+1)	0.509	300	-	12
Cc=0.01*(LL-10.9)	0.67	356	Undisturbed	14
Cc=0.00556*LL	0.932	26	-	19
Cc=0.0055*(LL-1.8364)	0.970	18	Remoulded	20
Cc=(0.014*LL)-0.168	0.776	947	Undisturbed	21
Cc=(0.007*LL)-0.043	0.592	78	Remoulded	22
Cc=0.014*PI	0.977	55	Remoulded	24
Cc=0.01706*(LL-1.30)	0.591	20	Undisturbed	25
Cc=(0.004*LL)-0.03	0.885	60	-	26
Cc=0.015*(LL-20)	0.717	51	-	28
Cc=(0.0067*LL)-0.0364	0.970	23	Remoulded	29

r:Correlation coefficient, N:Number of samples

Table 2: Previously suggested equations between Wn and Cc

Equation	r	N	Type of soil	Reference
Cc=0.01*(Wn-5)	0.790	717	Undisturbed	4
Cc=0.013*(Wn-7)	0.918	105	Undisturbed	5
Cc=0.0066*Wn	-	-	Undisturbed	8
ln Cc=(1.235*Wn)-5.65	0.803	300	-	12
Cc=0.013*(Wn-3.85)	0.73	278	Undisturbed	14
Cc=0.0092*Wn	0.972	26	-	19
Cc=0.0072*(Wn-12.625)	0.878	18	Remoulded	20
Cc=(0.013*Wn)-0.115	0.814	947	Undisturbed	21
Cc=(0.0074*Wn)-0.007	0.975	40	-	23
Cc=0.0102*(Wn+11.57)	0.488	20	Undisturbed	25
Cc=(0.002*Wn)+0.14	0.618	60	-	26
Cc=0.021*(Wn-17)	0.826	51	-	28

r:Correlation coefficient, N:Number of samples

Table 3: Previously suggested equations between e_0 and Cc

Equation	r	N	Type of soil	Reference
$Cc=0.4*(e_0-0.25)$	0.85	717	Undisturbed	4
$Cc=0.62*(e_0-0.56)$	0.918	105	Undisturbed	5
$Cc=0.7*(e_0-1.65)$	0.92	-	Undisturbed	7
$Cc=0.42*(e_0-0.5)$	-	-	Undisturbed	8
$\ln Cc=(1.272*\ln e_0)-1.282$	0.817	300	-	12
$Cc/n_0=(0.0115*Cc)+0.00269$	0.994	83	Undisturbed	13
$Cc=0.54*(e_0-0.37)$	0.77	278	Undisturbed	14
$Cc=1.02-(0.95*e_0)$	-	20	Remoulded	15
$Cc=0.2875*(e_0-0.5082)$	0.903	18	Remoulded	20
$Cc=(0.49*e_0)-0.11$	0.812	947	Undisturbed	21
$Cc=(0.286*e_0)-0.054$	0.914	78	Remoulded	22
$Cc=0.3921*e_0$	0.959	44	Remoulded	23
$Cc=0.5217*(e_0-0.20)$	0.653	20	Undisturbed	24
$Cc=(0.3608*e_0)-0.0713$	0.980	40	-	25

r:Correlation coefficient, N:Number of samples

Table 4: Previously suggested equations with multiple index properties and Cc

Equation	r	N	Type of soil	Reference
$Cc=0.37*(e_0+(0.003*LL)-0.34)$	0.860	678	Undisturbed	4
Cc=0.5*PI*Gs	-	-	Remoulded	6
$Cc=-0.156+(0.411*e_0)+(0.00058*LL)$	0.957	72	-	9
$Cc=-0.3-(0.0003*Wn)+(0.538*e_0)+(0.002*LL)$	0.830	278	Undisturbed	14
$Cc=-0.404+(0.341*e_0)+(0.006*Wn)+(0.004*LL)$	0.680	468	Undisturbed	16
$Cc=0.1597*(Wn^{-0.0187})*[(1+e_0)^{1.592}]*(LL^{-0.0638})*(\rho_d^{-0.8276})$	0.754	135	-	17
Cc=-0.077+(0.007*Wn)+(0.001*LL)	0.926	78	Remoulded	22
Cc=(0.016*Wn)+(0.007*LL)+0.481	0.864	51	-	28

r:Correlation coefficient, N:Number of samples

Table 5: Previously suggested equations with index properties and Cs

Equations	r	N	Type of soil	Reference
$Cs=0.0121*e^{(1.3131*e0)}$	0.806	42	Undisturbed	18
Cs=0.00087*Wn	0.987	26	-	19
Cs=-0.0214+(0.0013*LL)	0.943	344	Undisturbed	27

r:Correlation coefficient, N:Number of samples

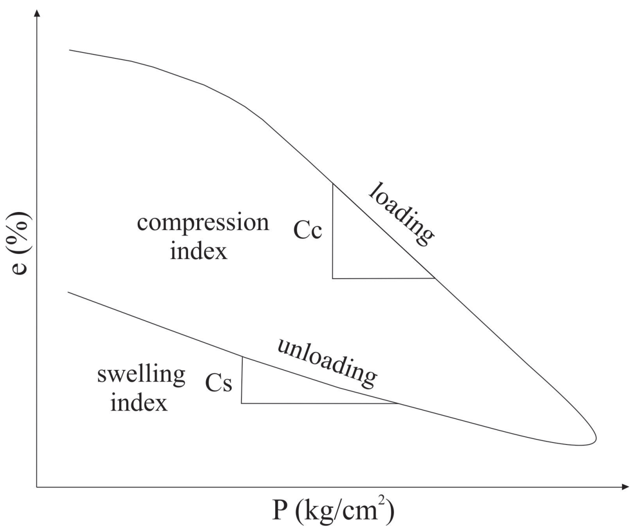

Figure 2: Graph of e-logP

used undisturbed marine sediments, while [20] have used remoulded marine samples to obtain Cc, and [17, 21, 23] have used artificial neural network (ANN) method.

In this study, both marine and terrestrial undisturbed samples, and subgroups at the Plasticity chart have been used. Moreover, the dial gauge used in this study has 0.002 mm resolution and it is more sensitive than those used at the previous studies. To test the significance of equations, T and F tests were performed. Within this study, a data set consisting of both marine and terrestrial undisturbed sediments have been used and statistically significant equations have been proposed.

2 Geological Setting

The study area is located at the western side of the Adana Basin, one of the major Neogene basins in the Taurus Orogenic Belt [30]. A thick lithostratigraphic units ranging in age from Oligecene to Recent, unconformably overlies the Palaeozoic and Mesozoic basement rocks in the Adana Basin [31]. In the study area, Tortonian aged Kuzgun Formation is widespread and some parts of the study area Quaternary aged delta deposits, caliche and alluvium units overlay the Kuzgun Formation (Figure 3) [32, 33]. Kuzgun Formation has four main units such as: sandstone-conglomerate, reef limestone, tuffite and claystone-marl-siltstone from oldest to youngest [33]. Quaternary units at the study area involve hardpan caliche, alluvium units and deltaic deposits [34]. Caliche, aged between 250 to 782 ka BP, is widely seen at Mersin area and present in a variety of forms such as, powdery, nodular, tubular, fracture-fill, laminar crust, hard laminated crust and pisolitic crust [35]. Alluvium units have occurred with the sediment deposition from Deliçay and Kızıldere Rivers. Delta Deposits accumulated with the sediment deposition to the depression zones, which were occurred at the Late Sicilien [33].

3 Method

To determine the relations of consolidation and index properties of soils, a data set consisting of 58 undisturbed samples, taken from southern parts of the Mersin City, has been constructed. 18 of the samples were taken from offshore drilling and 40 of them were taken from terrestrial drilling. Consolidation [2] and Atterberg Limit Tests [36] were performed on the samples. The parameters of the data set are compression index (Cc), swelling index (Cs), initial void ratio (e_0), liquid limit (LL), plastic limit (PL), plasticity index (PI), wet density (ρ) and natural water content (Wn). Four of the samples are non-plastic; so Atterberg tests could not be performed on them. Population standard deviation, skewness and kurtosis values were found with Eq. 1, 2 and 3 respectively, and shown in Table 6.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(X_i-\mu)^2}{N}} \tag{1}$$

$$S = \sqrt{N} * \frac{\sum_{i=1}^{N}(X_i-\mu)^3}{\left(\sum_{i=1}^{N}(X_i-\mu)^2\right)^{3/2}} \tag{2}$$

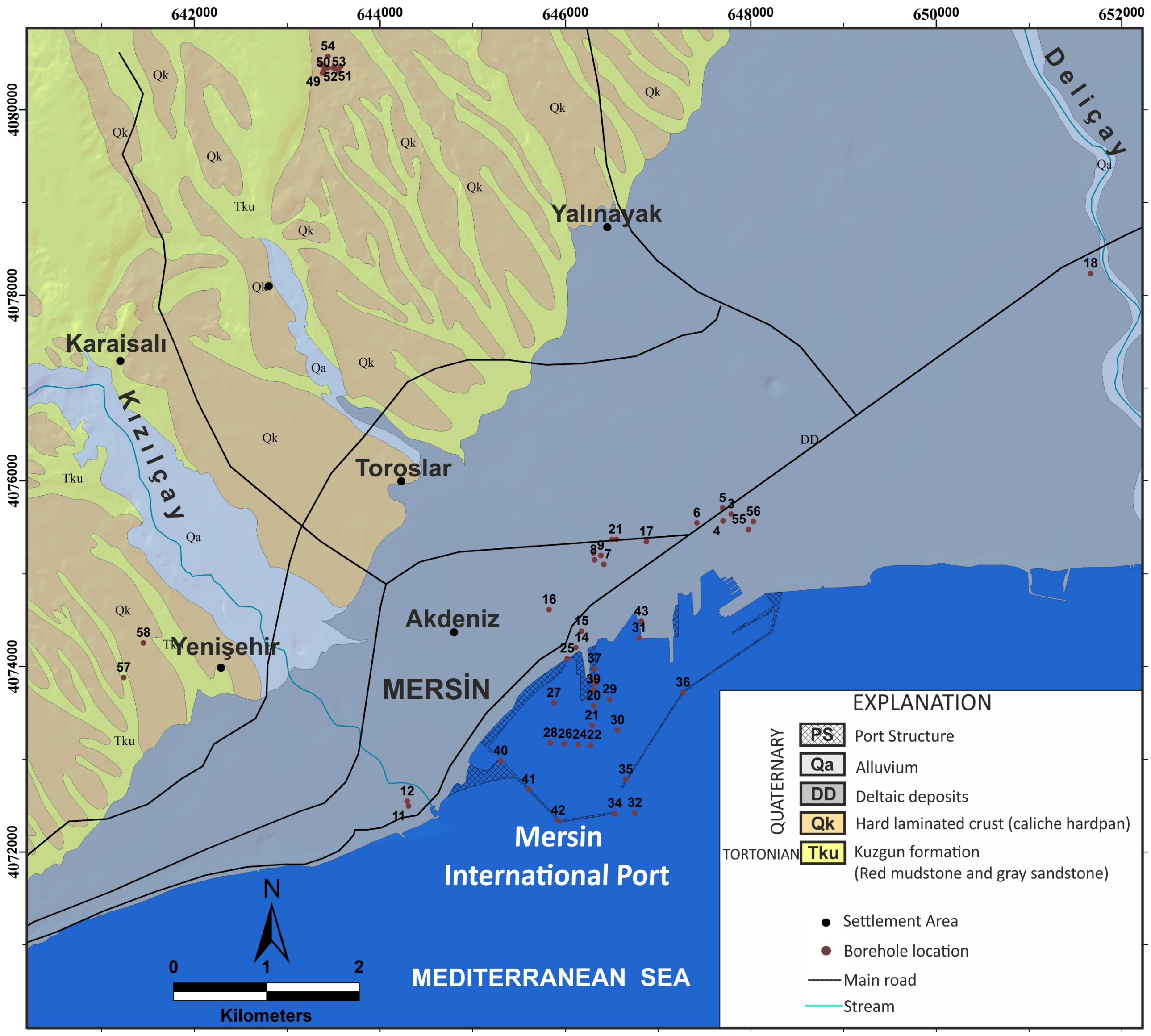

Figure 3: Geological map of the study area (UTM ED-50 zone 36 N) (Modified from [32, 33])

Table 6: Descriptive statistics of variables used in this study

Soil property	Count (N)	Minimum	Maximum	Average (μ)	Standard deviation (σ)	Skewness (S)	Kurtosis (K)
Cc	58	0.018	0.26	0.087	0.050	1.718	2.796
Cs	58	0.002	0.102	0.018	0.019	2.550	6.896
LL (%)	54	22.3	74.8	42.46	11.746	0.388	−0.569
PL (%)	54	10.1	37.2	18.36	5.301	1.319	2.357
PI (%)	54	7.0	55.1	24.09	10.062	0.745	0.180
ρ (g/cm^3)	58	1.715	2.385	1.944	0.120	0.974	1.473
e_0	58	0.213	0.9904	0.471	0.157	1.675	3.170
Wn (%)	58	15.38	39.5	23.22	4.722	1.002	1.058

Cc = Compression index, Cs = Swelling Index, LL = Liquid Limit, PL = Plastic Limit, PI = Plasticity Index, ρ = wet density, e_0 = initial void ratio, Wn = Natural water content

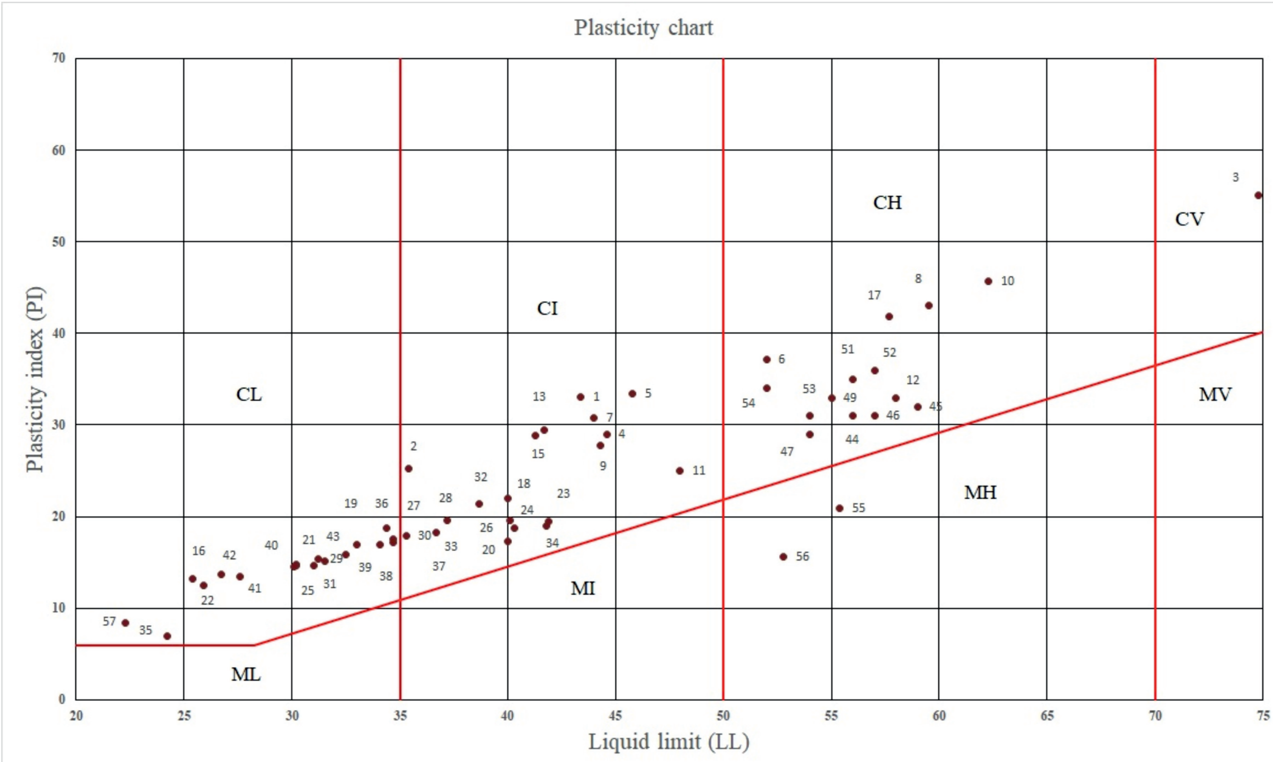

Figure 4: Plasticity chart

Table 7: Subgroups of the database

Subgroup	Explanation	N
CL	clay with low plasticity	18
CI	clay with intermediate plasticity	19
CH	clay with high plasticity	14
CV	clay with very high plasticity	1
MH	silt with high plasticity	2

$$K = N * \frac{\sum_{i=1}^{N} (X_i - \mu)^4}{\left(\sum_{i=1}^{N} (X_i - \mu)^2\right)^2} \quad (3)$$

where:
X_i = Sample
N: number of parameters
μ : average value
σ : population standard deviation
S: skewness
K: Kurtosis

The database was divided into subgroups according to the Plasticity chart (Figure 4). Each subgroup has its own chemical, physical and engineering properties and those properties may effect Cc and Cs values. The number of each subgroup is shown in Table 7.

4 Regression Analyses

In this study, simple and multiple regression analyses were done to the parameters at the database by using Microsoft Office Excel (2013) software. At simple regression equations, four different types of trendline options (linear, logarithmic, power and exponential) were drawn and the one which has higher correlation coefficient (r) was chosen.

Equations obtained to get Cc and Cs parameters with simple and multiple regression analyses are shown in Tables 8 and 9 respectively. The root mean square error (RMSE), mean absolute error (MAE) and variance account for (VAF) values were determined by Eq. 4, Eq. 5 and Eq. 6 respectively.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (y_i - y_i')^2}{N}} \quad (4)$$

Table 8: Obtained equations for Cc and Cs with simple regression analysis

Equation	r	N	RMSE	MAE	VAF	tcalculated	ttable
$Cc=0.0054*LL^{0.7102}$	0.385	54	0.049	0.031	13.29	3.01	2.01
$Cc=(0.0024*PL)+0.042$	0.249	54	0.050	0.038	6.20	1.85	2.01
$Cc=0.0196*PI^{0.4343}$	0.357	54	0.050	0.030	9.59	2.76	2.01
$Cc=(-0.061*\ln(\rho))+0.128$	0.074	58	0.050	0.036	0.54	0.56	2.00
$Cc=(0.2213*e_0)-0.0171$	0.692	58	0.036	0.029	47.91	7.17	2.00
$Cc=(0.0064*Wn)-0.0607$	0.598	58	0.040	0.031	35.72	5.58	2.00
$Cs=3*10^{-5}*(LL^{1.6})$	0.540	54	0.017	0.009	16.17	4.63	2.01
$Cs=(0.0009*PL)+0.0013$	0.254	54	0.017	0.012	6.42	1.89	2.01
$Cs=0.0005*(PI^{1.0355})$	0.531	54	0.017	0.009	12.47	4.52	2.01
$Cs=(-0.03*\ln(\rho))+0.0375$	0.093	58	0.019	0.013	0.85	0.70	2.00
$Cs=(0.0856*e_0)-0.0226$	0.695	58	0.014	0.010	48.33	7.23	2.00
$Cs=(0.0025*Wn)-0.0405$	0.611	58	0.015	0.011	37.35	5.78	2.00

r:Correlation coefficient, N:Number of samples, RMSE: Root Mean Square Error, MAE: Mean Absolute Error, VAF: Variance account for

Table 9: Obtained equations from multiple regression analysis

Equation	r	N	RMSE	MAE	VAF	Fcalculated	Ftable
$Cc=-0.09+(0.19*e_0+(0.004*Wn)+(0.0004*PL)$	0.787	54	0.034	0.027	61.82	27.08	2.79
$Cs=-0.05+(0.075*e_0)+(0.015*\rho)+(0.0003*LL)$	0.694	54	0.016	0.013	48.22	15.53	2.77

r:Correlation coefficient, N:Number of samples, RMSE: Root Mean Square Error, MAE: Mean Absolute Error, VAF: Variance Account For

Table 10: Obtained equations at subgroups with simple regression analysis

Equation	r	N	RMSE	MAE	VAF	tcalculated	ttable	Subgroup
$Cc=(0.1673*e_0)-0.0112$	0.595	18	0.020	0.016	35.42	2.96	2.12	CL
$Cs=(-0.033*\ln(PL))+0.0968$	0.583	18	0.0047	0.003	34.06	2.87	2.12	CL
$Cc=(0.2055*e_0)+0.0041$	0.844	19	0.021	0.017	71.29	6.49	2.11	CI
$Cs=2*10^{-5}*(PI^{2.0649})$	0.834	19	0.0069	0.005	56.42	6.23	2.11	CI
$Cc=(0.2945*e_0)-0.0649$	0.814	14	0.034	0.029	66.33	4.85	2.18	CH
$Cs=(0.1197*e_0)-0.0434$	0.800	14	0.0147	0.012	64.06	4.62	2.18	CH

r: Correlation coefficient, N: Number of samples, RMSE: Root Mean Square Error, MAE: Mean Absolute Error

$$MAE = \frac{\sum_{i=1}^{N} \left|(y_i - y_i')\right|}{N} \tag{5}$$

$$\mathrm{VAF} = [1 - \frac{var\,(y_i - y_i')}{var\,(y_i)}] * 100 \tag{6}$$

where y is the experimental result and y' is the predicted result.

Simple and multiple regression analyses were done to each subgroup and the results are shown in Tables 10 and 11, respectively.

5 Significance Tests

Significance tests with 5% significance level were done for both whole data set and subgroups. Two tailed t-test was performed for simple regression and t-values were calculated with Eq. 7. When the calculated value is larger than t_{table} value, the equation is statistically significant.

F-test with 5% significance level was performed for multiple regression analyses and F values were calculated by Eq. 8. When the calculated value of F is larger than the F_{table}, the relation is statistically significant.

$$t_{cal} = r\sqrt{\frac{N-2}{1-r^2}} \tag{7}$$

Table 11: Obtained equations at subgroups with multiple regression analysis

Equation	r	N	RMSE	MAE	VAF	Fcal	Ftable	Subgroup
$Cc=-0.58+(0.40*e_0)+(0.22*\rho)+(0.002*LL)$	0.899	18	0.012	0.010	80.66	19.67	3.34	CL
$Cs=-0.14+(0.09*e_0)+(0.05*\rho)+(0.0003*LL)$	0.901	18	0.007	0.007	80.74	20.12	3.34	CL
$Cc=-0.11+(0.14*e_0)+(0.004*Wn)+(0.002*PI)$	0.943	19	0.014	0.012	88.73	40.50	3.29	CI
$Cs=-0.005+(0.028*e_0)-(0.008*\rho)+(0.001*PI)$	0.900	19	0.004	0.004	80.91	21.28	3.29	CI
$Cc=0.48+(0.27*e_0)-(0.176*\rho)-(0.003*LL)$	0.891	14	0.031	0.027	79.42	12.91	3.71	CH
$Cs=-0.04+(0.132*e_0)+(0.03*\rho)-(0.003*PL)$	0.911	14	0.011	0.010	82.92	16.36	3.71	CH

r: Correlation coefficient, N: Number of samples, RMSE: Root Mean Square Error, MAE: Mean Absolute Error, VAF: Variance Account For

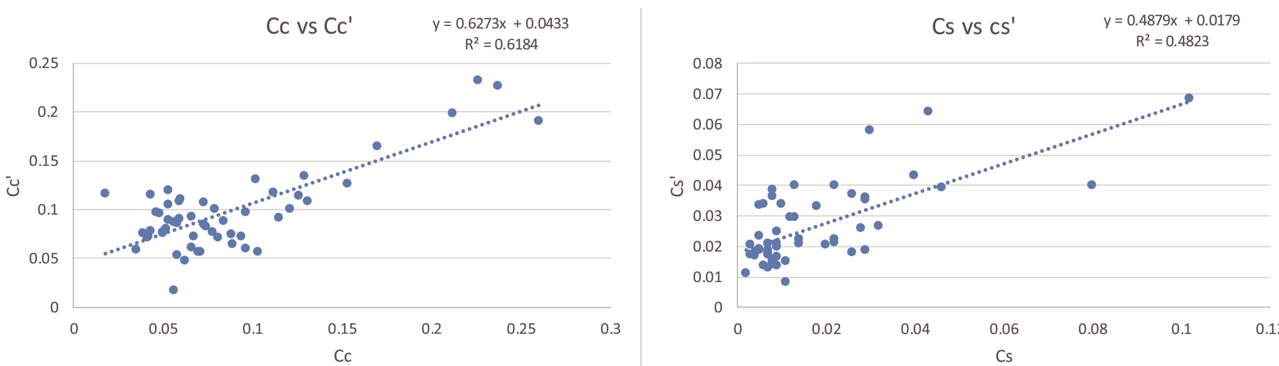

Figure 5: Measured vs calculated values of Cc and Cs with multiple regression analysis

$$F_{cal} = \frac{\left[\sum_{i=1}^{N}\left(y_i' - \bar{y}\right)^2\right] / K}{\left[\sum_{i=1}^{N}\left(y_i - y_i'\right)^2\right] / (N - K - 1)} \quad (8)$$

where y' is the predicted result, y is the experimental result, $\bar{y}$ is the average of y, K is degree of freedom.

6 Results

In this study, there are 3 main subgroups such as CL, CI and CH and the numbers of them are 18, 19 and 14 respectively (Table 7). With simple regression analysis, only e_0 parameter has given high r value with low RMSE and MAE to obtain both Cc and Cs parameters (Table 8). Wet density of the samples has given very low r values. With multiple regression analysis (Figure 5), slightly better r values than simple regression equations were obtained (Table 9). It is clear that equations with more than one parameter is more reliable. Simple regression analysis results of subgroups in Table 10 are slightly better than the whole data set. Very high r values at the subgroups have been obtained with multiple regression analysis in Table 11. RMSE and MAE values, indicating error amounts, have low values (Tables 8-11). To test the significance of equations, T-test have been used for simple and F-test have been used for multiple regression analyses. The obtained equations are statistically significant.

7 Discussion

Compression and swelling index parameters, obtained from undisturbed samples, are used to calculate settlement amount. Many researchers have used remoulded samples, and those samples cannot give real value. Many equations have been suggested previously to obtain Cc parameter with Atterberg limits as seen in Table 1. However, there are certain inconsistencies between the correlation coefficients. The reasons of them are the type, the number of soil at the database and the precision of the equipment to perform consolidation and Atterberg tests at that year. Park and Lee [21] have found high r value (0.776), whereas in this study low r value (0.385) has been found (Table 8).

Equations between Wn and Cc parameters are seen in Table 2, some of which have very high r values. Kogure and Ohira [5] have found high r value (0.918) from 105 undisturbed samples. In this study, low r value (0.598) has been obtained between those two parameters (Table 8).

Equations between e_0 and Cc parameters have high r values (Table 3), for example Park and Koumoto [13] have found very high r value (0.994) from initial porosity ($e_0/1+e_0$). In this study, low r value (0.692) has been obtained with 58 undisturbed samples (Table 8).

Equations with multiple index properties to obtain Cc parameter are seen in Table 4. These are slightly better than equations obtained from simple regression analysis. The correlation coefficients of the previously suggested equations in Table 4 are nearly the same to the ones at this study (Table 9).

Equations between Cs and index properties of samples have high r values (Table 5). Kordnaeij *et al.* [27] have found very high r value (0.943) with only LL value. In this study, by using simple regression analyses, low r values have been obtained (Table 8).

Descriptive statistics of the database is shown in Table 6. The number of the samples is 58, which is enough to perform simple and multiple regression analyses. Regression analysis may give more reliable equations when more samples and wide spectrum of parameters are used in the analysis. Standard deviation is higher at LL, and lower at Cs. Skewness is higher at Cs and lower at LL. Kurtosis value is higher at Cs and lower at PI.

Researchers have proposed equations between index tests and consolidation test parameters by using whole data set. In this study, subgroups have been used and very high correlation coefficients have reached. So, our findings are more reliable than previously suggested ones.

There has to be exactly matched equations between consolidation and index test parameters. Only the parameters obtained from Atterberg tests, initial void ratio, wet density and natural water content are not enough to obtain accurate equations. There needs to be another parameters in the equations. Grain size distribution and chemistry of soil may have an effect on compressibility. Various grain size and chemical composition of the samples from different geological formations in the study area may have an effect to the Cc and Cs values.

When the consolidation test could not be performed, it is a good way to use more than one equation from Tables 8-11 and get the average value to predict the compression parameters of soils.

8 Conclusion

In this study, combination of marine and terrestrial Quaternary sediments was used, and statistically significant equations with high correlation coefficient were proposed. Studies show that there is no equation that fully explains the relations between consolidation and index properties of soils. However, the obtained equations are very close to the actual values of Cc and Cs. Statistically significant equations with high r and VAF values and low RMSE and MAE values are were obtained from subgroups of Plasticity chart with multiple parameters. Those equations can be used to predict Cc and Cs parameters when the conditions are not suitable to perform consolidation test.

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