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Studies on the Characteristics of Marine Clay at Puducherry along the East Coast of India

R.Saisubramanian [1] V.Murugaiyan [2] T.Sundararajan[3]
1. Department of Civil Engineering, Research scholar, Pondicherry Engineering College, Puducherry, India
2. Department of civil Engineering, Professor, Pondicherry Engineering College, Puducherry, India
3. Department of Civil Engineering, Professor (retired), Pondicherry Engineering College, Puducherry India
Corresponding Author: R.Saisubramanian e-.mail:sai_radhika1@yahoo.co.in

ABSTRACT: Several studies have been carried out for determining the characteristics and application of soft and marine clay all over the world. Most of the works are done to address a specific requirement such as strength for construction of offshore facilities like port development. In this study an attempt has been made to tabulate the marine clay characteristics at Puducherry along the east coast of India covering a distance of about 50 km along the coast line at an average distance of 2.0 km landward of shoreline. The studies focussed on the influence of creeks and backwaters near Puducherry, India. It has been found that the impact of coastal environment has extended up to 2.0 km form the shore line. The characteristics studied are Liquid Limit (LL), Plastic Limit (PL), Shrinkage Limit (SL), Free Swell Index (FSI), Salinity,and pH, Natural Moisture Content (NMC), Compression Index (CI) and Specific Gravity (G). The ratio of Plastic Limit to Liquid Limit of the soil varied from 0.48 to 0.59 indicating the characteristic of marine clay at depth varying from 1m to 12 m both adjacent to the backwaters and away from it .The Salinity ranged from 1-13%. pH is in the range of 7.1 to 7.9.Model studies of the relationship among the parameters studied by statistical evaluation of soil data suggest linear relationship between Liquid Limit and Plastic Limit with coefficient of Regression R^2 value of 0.839. The Compression Index bear polynomial relation with Plastic Limit with R^2 value of 0.906 and Natural Moisture Content with an R^2 Value of 0.539. The logarithmic relationship between Free Swell Index (FSI) and Plasticity Index (IP) exhibit a R^2 value of 0.665.
Key words: Marine clay, Compression index, Model Analysis, Coefficient of Regression.

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I. INTRODUCTION

Marine clay characterisation is important for understanding the compressibility and strength behaviour and for deciding the strength improvement methods that can be adopted for achieving the desired strength. Marine clay can be identified by examining the engineering properties. Typically marine clay would exhibit a ratio of plastic limit to liquid limit between 0.4 to 0.6[1], while in some places like Ariake bay around Japan , this ratio is between 0.35-0.5[2].Marine clay in cochin has a range varying from 0.34 to 0.53[3]-[6]. Range of pH is in of the order of 7.2to 8.3. Salinity is around 5.0g/l to 7.3g/l [7]. The strength of marine clay is usually low rendering it absolutely necessary to improve it in order to carry out any construction activity. One of the frequently resorted method is to make use of additives such as lime [8], cement ([9], [10]), fly ash [11], [12] and Granulated Blast Furnace Slag (GBFS) [13], [14]. The offshore profile of coast line of east coast of India is having major clay layers at depth below 15 m in Calcutta and it is formed at the sea level in other places such as in Orissa ,Andra Pradesh and in Palk strait [15]. It has always been the endeavour of geotechnical engineers to simplify the rigorous testing by establishing prediction model for soil using the basic parameters .Many attempts have been made to establish relationship among the basic parameters of expansive soils, marine clay and stabilised soils for prediction of strength and compressibility using statistical measures such as regression analysis , correlation index and random filed theory[17]-[20].The relationship between the parameters like liquid limit moisture content , friction angle exhibit a distinct range when prediction of N value is related to the measured value using Swedish sounding test[21].Principal component analysis and the findings of principal component analysis indicating the factor loadings among the variables when used for predicting strength parameters using Artificial neural networks (ANN) yield more closer and reliable prediction[22].

Study Area

Puducherry shares a coast line for a length of about 48 km in its territory with the neighbouring state of Tamilnadu along the east coast of India. Geological studies [16] indicate that a good part of the terrain in Puducherry covered by alluvium of varying thickness has the potential to have marine clay deposits of varying thickness: Bahour to katterikuppam 20-35 m, Tavalakuppam 18 m, Bahour – kattukuppam area 20-35 m and Villianur - Ellapillaichavady 22-38 m.With the potential of marine clay, the study area has been worked out by selecting sampling stations to reflect the impact on marine by considering very distinct situations. Sample location details are given in Table 1.

Table 1. Details of sampling stations

Sampling station	Location	Latitude	Longitude
1	Near Salt Pan on west of ECR at Marakanam	12°12′49″N	79°58′17.2″E
2	ECR near Sivaji statue (Pump house site)	11°57′22″N	79°49′32″E
3	Near Bharathipuram water tank	11°55′54″N	79°49′22″E
4	Thengaithittu near Harbour	11°57′22″N	79°49′32″E
5	Ariyankuppam river bund behind Arts & Crafts village building	11°54′2″N	79°48′43″E
6	Chunnambar south of Boat house (sea side) East of bridge	11°52′48″N	79°48′1″E
7	Chunnambar on fresh water side West of bridge	11°57′22″N	79°49′32″E
8	Near Canal on Mullodai road west of ECR	11°52′42″N	79°47′49″E

II. METHODOLOGY

Disturbed samples were collected from boreholes at every meter and at the layers where there is a change in soil profile. The samples were tested to determine Liquid Limit, Plastic Limit, Shrinkage Limit, Shrinkage Index, Free Swell Index, pH, Natural Moisture Content, Salinity, Swell % and Compression Index. The ratio of Plastic Limit to Liquid Limit which is in the range of 0.48 to 0.59 at all locations of sampling indicates the characteristic of marine clay. Though the location of sampling locations are at a distance varying form 0.5 km -2.0 km from the shoreline, the observed values Plasticity Index , Liquid Limit, pH and Salinity share the range of similar parameters of marine clay. The soil parameters at different depth are given in Table 2.

Table 2.Soil parameters at different depth in various sampling stations

Depth (m)	LL (%)	PL (%)	SL (%)	SI (%)	IP (%)	FSI (%)	G ($g/cm^{3)}$	NMC (%)	pH	Salinity %	CI	PL/LL
7	51	28	10.26	17.74	23	70	2.55	35	7.5	8	0.37	0.55
8	58	31	11.33	19.67	27	80	2.46	40	7.4	7	0.43	0.53
9	62	32	10.58	21.42	30	91	2.49	40	7.6	7	0.47	0.52
10	60	32	12.62	19.38	28	90	2.51	36	7.5	9	0.45	0.53
11	61	30	11.59	18.41	31	90	2.51	43	7.6	8	0.46	0.49
0.5	73	35	12.86	22.14	38	100	2.38	38	7.3	50	0.57	0.48
2	60	32	14.28	17.72	28	98	2.38	33	7.5	2	0.45	0.53
3	73	43	19.62	23.38	30	100	2.44	41	7.3	3	0.57	0.59
4	72	41	16.10	24.90	31	100	2.41	40	7.3	3	0.56	0.57
5	72	42	18.22	23.78	30	100	2.46	43	7.4	3	0.56	0.58
7	72	41	17.10	23.90	31	134	2.57	37	7.8	3	0.56	0.57
3	65	33	16.56	16.44	32	123	2.52	38	7.8	3	0.5	0.51
5	64	31	15.61	15.39	33	142	2.46	46	7.9	4	0.49	0.48
9	63	32	14.65	17.35	31	140	2.46	40	7.7	11	0.48	0.51

10	65	32	15.41	16.59	33	124	2.44	38	7.9	10	0.5	0.49
10	60	31	15.30	15.70	29	100	2.58	38	7.8	7	0.45	0.52
11	64	35	14.95	20.05	29	100	2.55	42	7.7	7	0.49	0.55
12	62	32	14.62	17.38	30	110	2.61	39	7.7	8	0.47	0.52
7	65	33	15.56	17.44	32	134	2.55	38	7.6	8	0.5	0.51
8	70	38	16.20	21.80	32	140	2.48	45	7.5	10	0.54	0.54
9	73	38	17.80	20.20	35	147	2.52	50	7.5	10	0.57	0.52
10	69	36	15.20	20.80	33	137	2.49	55	7.3	9	0.53	0.52
11	75	40	15.99	24.01	35	150	2.51	51	7.5	8	0.59	0.53
12	70	38	17.12	20.88	32	150	2.52	48	7.4	9	0.54	0.54
1	42	22	9.16	12.84	20	55	2.53	30	7.3	1	0.29	0.52
7	52	26	12.56	13.44	26	142	2.45	31	7.3	5	0.38	0.50
8	62	31	13.95	17.05	31	138	2.63	42	7.1	6	0.47	0.50
9	60	29	14.45	14.55	31	139	2.48	40	7.2	6	0.45	0.48

Mineralogical study

Samples of soil are tested for determining the type of clay mineral using standard x-ray diffraction (XRD) analysis. Each and every mineral has different concentration as reflected in the intensity of XRD. Peaks observed at 26.52 Å and 19.66 Å is identified as kaolinite followed by small fraction of zeolites. A typical XRD pattern is given in Figure.1

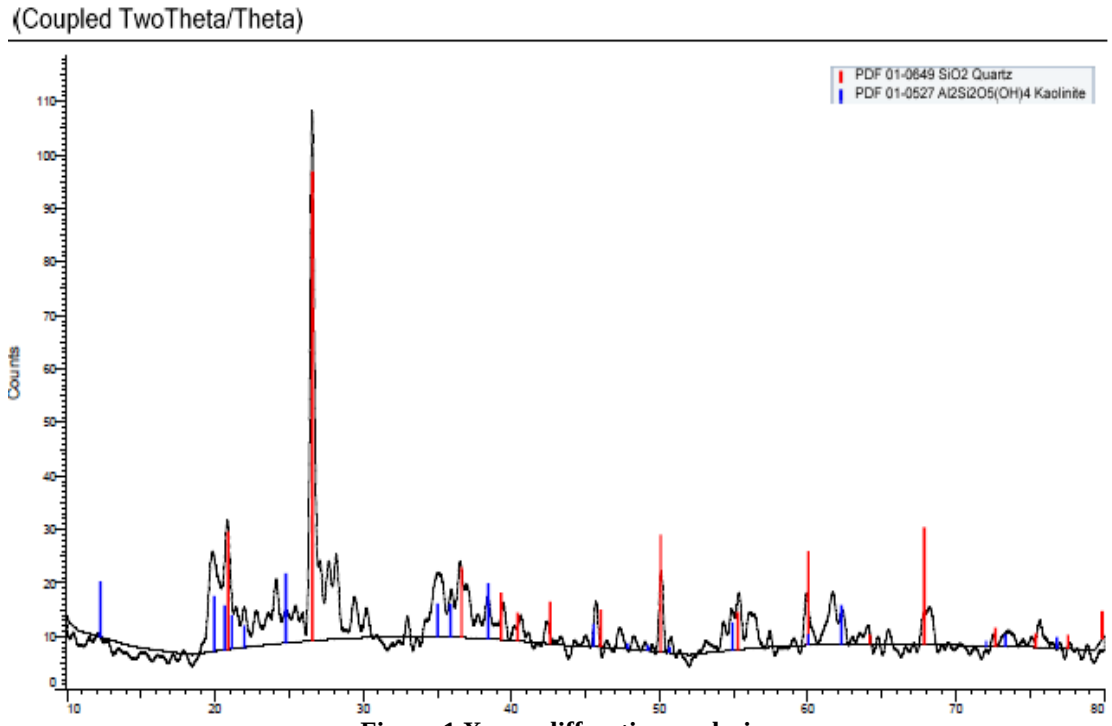

Figure 1.X- ray diffraction analysis

The Scanning Electron Microscope (SEM) analysis has been carried out to determine the shape and arrangement of the minerals present. The typical sample is given in figure 2 exhibit shape of a small sphere. The approximate particle size is 100 nm to 200 nm.

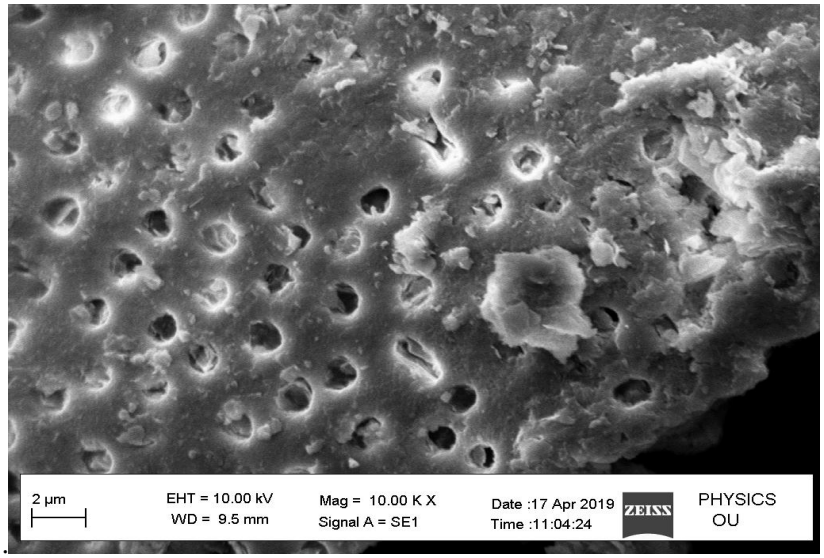

Figure 2. Typical shape of particles

In addition to XRD and SEM analysis Energy Dispersive X-ray Analysis (EDAX) was conducted on representative specimen. EDAX analysis indicates the presence of Aluminium, Silica, calcium and Potassium. A typical finding of minerals present as identified by EDAX is given in Figure3.

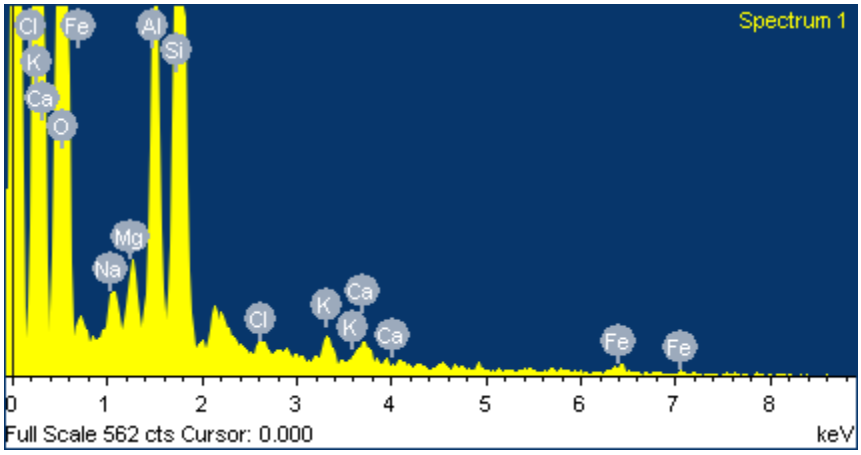

Figure3 .EDAX analysis for mineral composition

Statistical Studies

It has always been the endeavour of geotechnical engineers to simplify the rigorous testing and the complex data interpretation for better comprehension of soil parameters using statistical techniques by establishing prediction model with basic soil parameters. In this study an attempt has been made to establish relationship among the basic parameters of expansive soils for prediction of strength and compressibility using statistical measures such as Descriptive statistics, Correlation Analysis, Regression Analysis, Distribution Analysis, Analysis of Variance (ANOVA) etc. using statistical package SPSS Version 21 and XLSTAT Version 2016.

Descriptive Statistics

In the Descriptive Analysis more frequently considered soil parameters were evaluated. The main objective of the descriptive analysis is to understand the pattern of variation of the soil characteristics such as liquid limit, plastic limit, shrinkage limit, free swell index, compressive index etc., and to establish a platform for comparison of soil characteristics .A quantitative statistical measure such as mean, median, standard deviation, range, kurtosis and skewness would be a tool for assessment of suitability of soil for any desired purpose. The result of the descriptive study is given in Table 4.The wide range of salinity in the analysis, is due to high value observed in the sample from salt pan.

However salinity value of soil samples at different depth from a borehole with in 50 m from the active salt pan is observed as 8% at a depth of 7m.The variation in salinity increase 9% up to a depth of 11m which is similar to the pattern of variation in salinity at other locations considered for analysis. Further the pattern of variation in salinity indicate that the presence of salt pan is not having any influence on the salinity of soil in the nearby location. The values of LL which is in the band of 50%-70% indicate that the clay is having "High" degree of expansion potential. The SL values share similar range with the Cochin marine clay which is also in the order of 18% to 21% [3]. Similarly the values of salinity also match with that of marine clay in Cochin. The LL has a mean value of 64.11, with third quartile of 70.50.This matches closely with the LL of marine clay at Changi, Singapore [23]. Important physical attributes taking cognizance of overall geological and environmental factors are assessed and presented in Table 3.

Table 3.Descriptive statistics

Statistic	LL (%)	PL (%)	SL (%)	SI (%)	IP (%)	FSI (%)	NMC (%)	pH	Salinity %	CI	Swell %	PL/LL
Minimum	42.00	22.00	9.16	12.84	20.00	55.00	30.00	7.10	1.00	0.29	3.23	0.48
Maximum	75.00	43.00	19.62	24.90	38.00	150.00	55.00	7.90	50.00	0.59	15.46	0.59
Range	33.00	21.00	10.46	12.06	18.00	95.00	25.00	0.80	49.00	0.30	12.23	0.11
1st Quartile	60.00	31.00	12.80	16.94	29.00	99.50	38.00	7.30	3.75	0.45	7.99	0.51
Median	64.00	32.00	15.08	18.90	31.00	116.50	40.00	7.50	7.00	0.49	9.41	0.52
3rd Quartile	70.50	38.00	16.13	21.52	32.00	139.25	43.00	7.70	9.00	0.55	10.16	0.54
Mean	64.11	33.71	14.63	19.08	30.39	115.14	40.61	7.51	8.04	0.49	9.17	0.52
Standard deviation (n)	7.50	4.92	2.47	3.27	3.50	26.03	5.63	0.21	8.53	0.07	2.39	0.03
Variation coefficient	0.12	0.15	0.17	0.17	0.12	0.23	0.14	0.03	1.06	0.14	0.26	0.06
Skewness (Pearson)	-0.85	0.04	-0.35	0.02	-0.81	-0.38	0.53	0.15	4.19	-0.83	-0.04	0.48
Kurtosis (Pearson)	0.84	-0.27	-0.36	-0.91	1.68	-0.89	0.30	-0.86	18.02	0.77	1.09	-0.43
Standard error of the mean	1.44	0.95	0.48	0.63	0.67	5.01	1.08	0.04	1.64	0.01	0.46	0.01

Skewness and Kurtosis

The Skewness value of all parameters fall between -1 to +1 except for salinity .In other words they are moderately skewed , barring salinity which is highly skewed and is due to 50 % soil salinity observed for the sample collected from salt pan. The LL, SL, IP, FSI, CI and Swell % follow Left tailed distribution (Skewness <0) while PL, SI, NMC, pH, Salinity, PL/LL follow right tailed distribution. (Skewness >0).

The Value of Kurtosis for all parameters studied with Kurtosis value < 3 are Platikurtic, except for salinity which has a kurtosis value of 4.19 and hence salinity is leptokurtic. If the salinity % from the salt pan which is 50 % is taken as an exception to the soil profile studied, then this would also be Platykurtic.

Test of Normality

For the study of statistical distribution of the variables, commonly adopted method is to conduct Shapiro-Wilk test particularly when the sample size is less than 50. Null hypothesis (H_0) and alternate hypothesis (H_1) are resorted to test the normal distribution. Shapiro-Wilk, Anderson – darling, Lilliefors and Jarque - bera test results conducted on the significant soil parameters are given in Table 4.

The assumptions are as below.

H_0 : Null Hypothesis : The data follow normal distribution.

H_1 : Alternate hypothesis : The data do not follow normal distribution.

Table 4.Test of Normality

Variable\Test	Shapiro-Wilk	Anderson-Darling	Lilliefors	Jarque-Bera
LL (%)	**0.037**	0.076	0.094	0.125
PL (%)	0.269	0.090	**0.038**	0.955
SL (%)	0.719	0.452	0.338	0.698
SI (%)	0.604	0.694	0.366	0.619
IP (%)	0.061	**0.032**	**0.036**	**0.041**
FSI (%)	**0.026**	**0.011**	**0.011**	0.451
pH	0.285	0.208	0.226	0.617
Salinity %	< **0.0001**	< **0.0001**	< **0.0001**	< **0.0001**
CI	0.061	0.133	0.143	0.143
Swell %	0.329	0.131	0.211	0.497
PL/LL	0.348	0.512	0.851	0.521

In the soil samples for p-value > 0.05, H_0 (Null Hypothesis) is accepted. Accordingly, from the Shapiro –Wilk analysis, the parameters PL, SL, SI, IP, pH, CI, Swell%, and PL/LL follow normal distribution. But LL, FSI and Salinity are not normally distributed. However LL and FSI are logarithmically distributed and Salinity follow log normal distribution.

Correlation Analysis.

Correlation coefficients is a common, simple and widely used measure to measure and establish the relationship between two variables indicating the degree of dependency of one variable with the other. Linear correlation between various parameters is determined between +1 and -1, and when the correlation co-efficient of a parameter is close to +1 or -1, the relationship between the variables is significant. Positive correlation indicates common evaluation pattern and features between different properties of soil. Based on the parameters that have been considered for analysis, a curve fit procedure for linear model has been adopted to find out the possible correlation between selected parameters, using Karl Pearson Correlation. The correlation matrix of the parameters is given in Table 5.

Table 5. Correlation matrix (Pearson)

Parameter	LL (%)	PL (%)	SL (%)	SI (%)	IP (%)	FSI (%)	NMC (%)	Salinity %	CI
LL (%)	1								
PL (%)	0.92	1.00							
SL (%)	0.79	0.81	1.00						
SI (%)	0.79	0.89	0.46	1.00					
IP (%)	0.84	0.58	0.56	0.44	1.00				
FSI (%)	0.51	0.33	0.59	0.05	0.64	1.00			
NMC (%)	0.66	0.55	0.48	0.47	0.64	0.54	1.00		
Salinity %	0.27	0.05	-0.14	0.18	0.51	0.00	0.06	1.00	
CI	1.00	0.92	0.79	0.79	0.85	0.52	0.66	0.27	1.00
Swell %	0.81	0.53	0.51	0.42	0.99	0.60	0.62	0.59	0.82

The degree of correlation is considered as Perfect Correlation (r = 0.9 to1.0), Very Good Correlation (r = 0.8 to 0.9), Good Correlation (r = 0.7 to 0.8) and Moderate Correlation (r=0.5 to 0.7) between the variables. The correlation value of more than 0.5 has been considered for building models considering the parameters involved. The relationships among the parameters depending on the degree of correlation are consolidated in Table 6.

Table 6.Degree of Correlation among Parameters

Correlation	Relationship among Parameters
Perfect(0.9 to 1)	a)LL with PL and CI b)PL with CI, c)IP with Swell %
Very Good (0.8 to 0.9)	a)LL with IP and Swell %, b)PL with SL and SI, c)IP with CI, d)CI with Swell %
Good (0.7 to 0.8)	a)LL with SL and SI,b)SL with CI, c)SI with CI
Moderate (0.5 to 0.7)	a)LL with FSI and NMC, b)PL with IP, NMC, and Swell %, c)SL with IP, FSI and Swell %, d)IP with FSI and NMC, e)FSI with CI, NMC and Swell %, f)NMC with CI and Swell %, g)Salinity % with Swell %

Regression Analysis:

A Statistical method like regression model is best suited for establishing relationship between dependant and one or more independent variables. Linear regression and nonlinear regression models were used to develop models relating most significant Parameters The most significant regression models for predicting LL, PL, IP, CI and FSI are presented in Table 7.The least R^2 value of 0.389 is for the model for PL with FSI second degree polynomial function .The highest R^2 value of 0.907 has been obtained for CI with PL being nonlinear polynomial model. In this model 90.7% of variance has been explained.

Table 7.Modelling between the soil parameters

Sl.no.	Model	R^2	Best fit Model
1.	PL =0.527LL	0.839	Linear
2.	$PL=0.572(IP)^2+4.278(IP)$	0.601	Second degree Polynomial function
3.	$PL=0.0511(FSI)^2+4.6902(FSI)-37.28$	0.389	Second degree Polynomial function
4.	$LL=0.8345(IP)^{0.8639}$	0.768	Power function
5.	$LL=-0.0604(FSI)^2+9.1417(FSI)-219.3$	0.749	Second degree Polynomial function
6.	$LL=1.7413(NMC)^{0.756}$	0.439	Power function.
7.	$IP=3.1856(NMC)^{0.7443}$	0.455	Power function
8.	$CI=0.005(PL)^2+0.0474PL-0.5146$	0.907	Second degree Polynomial function
9.	$CI=-0.0005(NMC)^2+0.0501(NMC)-0.7041$	0.539	Second degree Polynomial function
10.	$FSI=0.7977(IP)^{1.4509}$	0.665	Power function.

The pictorial representation of the models for more frequently used soil parameters for determination of strength, shear and to understand the compression and plasticity of expansive soils are graphically given in Figures 4 through Figure 9.

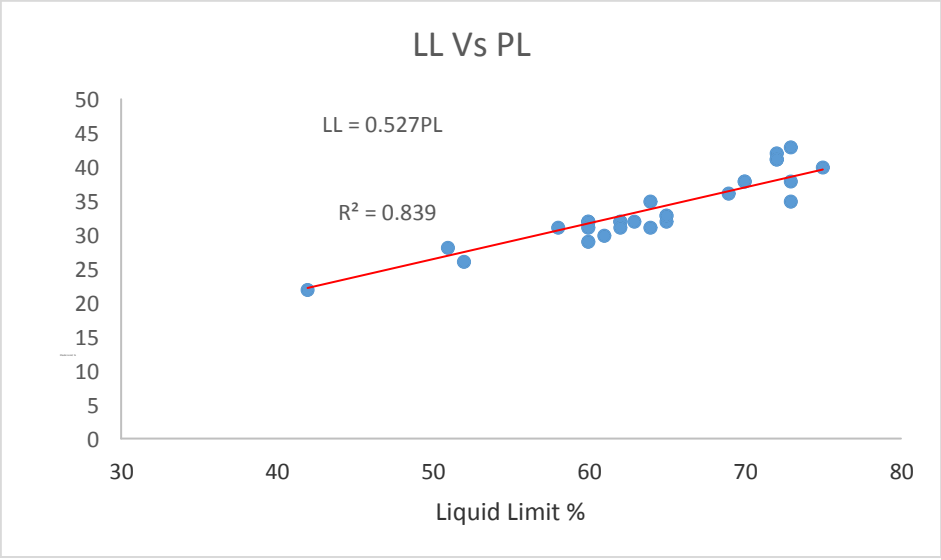

Figure 4 LL vs PL

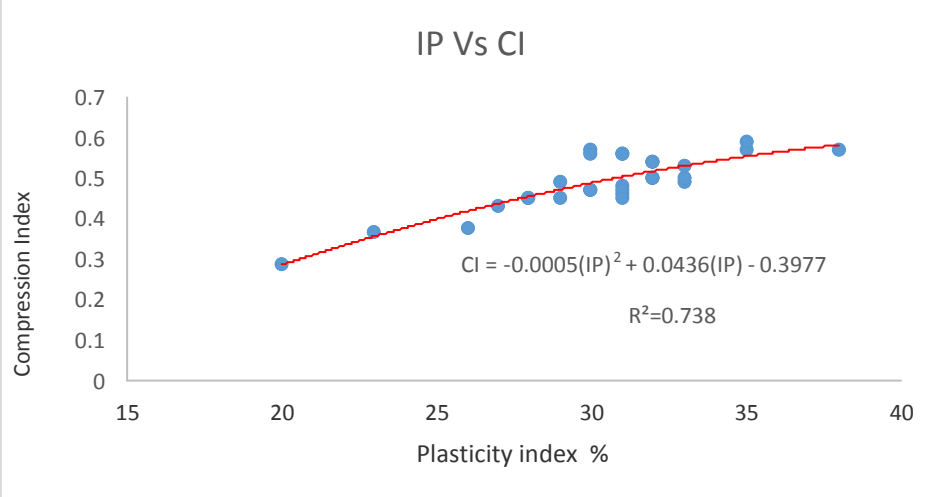

Figure 5.IP vs CI

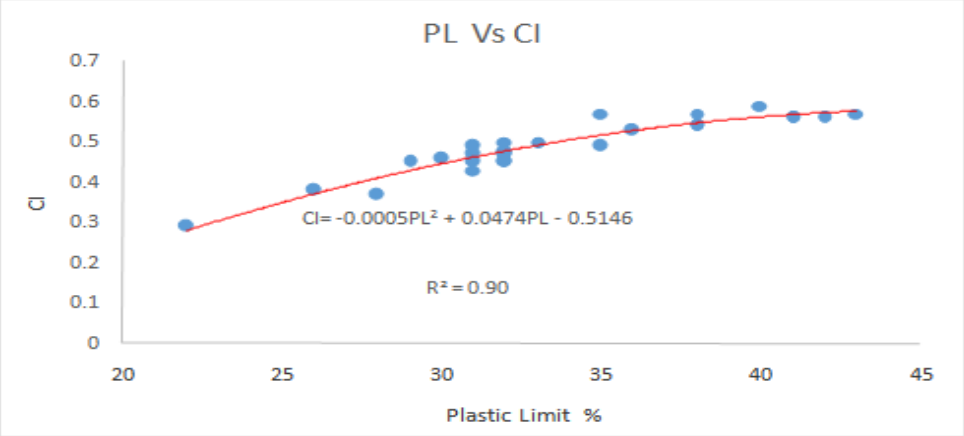

Figure 6 .PL Vs CI.

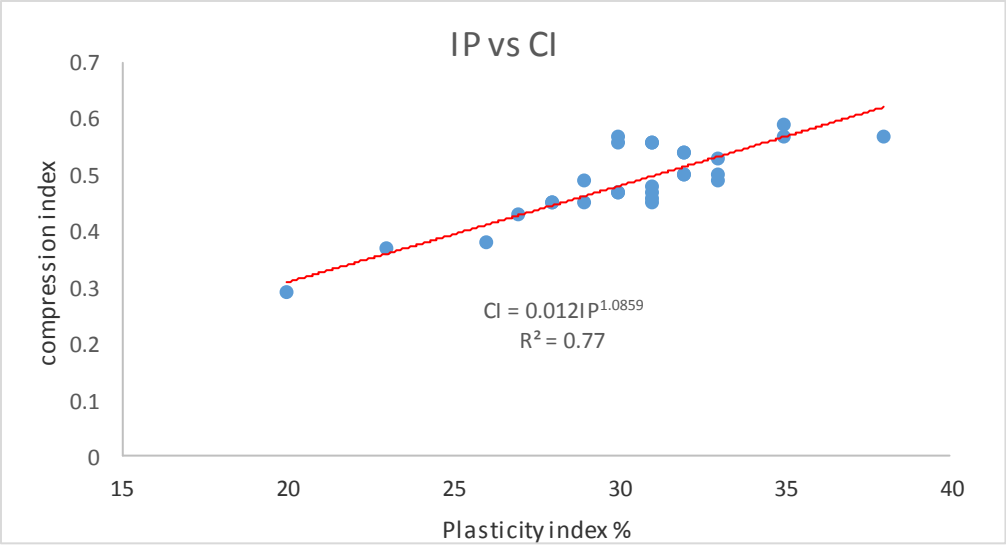

Figure 7 .IP Vs CI .

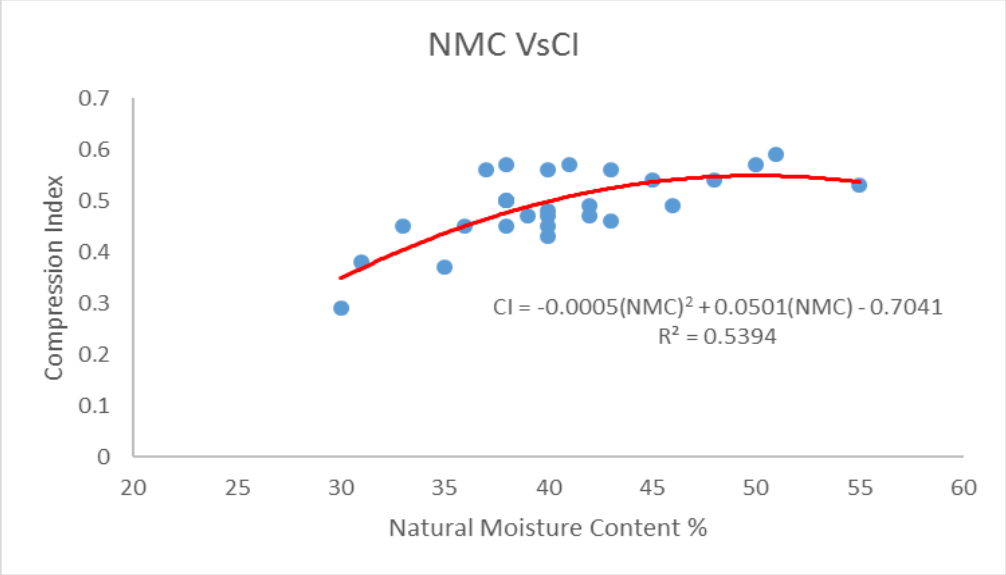

Figure.8 NMC Vs CI.

Concluding remarks:

The study has examined soil parameters from the sampling stations spread over a length of 50 km along the east coast skirting the puduchery,India. From the more relevant parameters that are determined from the soil samples collected from different depths, the following inferences are made.

1. The presence of marine clay indicated by the engineering properties .The ratio of Plastic Limit to Liquid Limit at all sampling locations and at different depths investigated vary from 0.48 to 0.58 which is the range of 0.4 to 0.6 an indicator of marine clay .This feature is seen all along the coast line investigated covering a distance of about 50 km even though the sampling stations also are physically located at distances varying form 0.5 km to about 2 km from the shore line. The study indicate that the parameters of LL which is more than 50% at most of locations and the Plasticity Index of over 25 also is in conformity with CH classification as per the Indian standard code of practice IS 1498-1970.
2. The pH value which is in the range of 7.0 to 7.6 an indicator of marine clay property.
3.The salinity in all the bore holes at different depth which vary from 1% -13% also imply increase in the salinity with depth , a possible impact of presence of backwaters.
4. The Salinity of soil collected from the salt pan is 50%, while the soil from the adjacent borehole up to 12m depth vary from 1% to 13% indicating an increase in salinity with depth as in other locations.
5. All basic descriptive statistics have been determined .The skewness indicate that most parameters are moderately skewed exhibiting left tailed distribution and right tailed distribution .Similarly Kurtosis values indicate that all parameters are Platykurtic .In both Skewness and Kurtosis analysis , salinity % stood out indicating high skewness and turned out to be Leptokurtic , due to the high value of single value of salinity of soil collected from saltpan, which was determined to be 50%.
6. Modelling table gives a handy tool for finding out the parameters with reasonable accuracy in view of the coefficient of determination and can be used for computing compressibility.

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