Compression Index of Cohesive Soils and Its Prediction

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Abstract **- For cost effective and safe constructions of foundations at sites having deposits of fine-grained soils within the zone of influence due to new construction, evaluation of consolidation settlement assumes great importance. The Compression Index (Cc) of the affected soils within the zone of influence need to be known for such evaluation. Such estimation is made generally on the basis of results of consolidation tests made on undisturbed soil samples collected from specified depths at the site. Collections of such soil samples require high cost, and complex sampling device which requires high skilled operator, time, and proper care for the device. The degree of disturbances created during sampling, transportation from field to laboratory and preparation of sample for test, are also unknown. Further soils in general and alluvial soils in particular are very erratic and only limited number of boring in the field and corresponding limited number of consolidation tests may not provide sufficient information to the designer for mapping variation in the consolidation characteristics of the soils. As a result, from a long period of time, several attempts have been made in past to predict the Cc using index properties, which are relatively easier to determine taking lesser time to test in laboratory. In this work, attempts have been made to check the efficacy of available correlations in literature by comparing predicted values with experimental test results on soils collected from different locations around Kolkata on two sides of Hooghly River in South Bengal. This work highlights the need for establishing more reliable correlation for Compression Index.**

Index Terms **- Compression Index (C_c), Index Properties, Alluvial Soils, Settlement.**

I.INTRODUCTION

A civil engineering structure is to be supported on soil or rock on earth surface depending on type of material at the location of construction. In plains the materials available at the construction sites are in general soils. For designing, properties of the affected mass of soil due to new construction must be properly estimated for safety and cost effectiveness of the chosen foundation system. Proper soil exploration program within the affected zone due to new construction must be made and proper field test like standard penetration test and collection of undisturbed samples and subsequent suitable laboratory tests must be performed.

In above testing program some of the tests can be done easily within a short time requiring simple testing arrangement and requiring only representative samples from the field (examples are test for grain size distribution, liquid limit, plastic limit, and specific gravity for soil solid). On the other hand, to estimate important soil properties in in-situ conditions, like strength of soil, consolidation property or permeability of the soil, costly undisturbed samples must be procured. For evaluation of resulting settlements, compression index (C_c) of compressible soils of each stratum within the zone of influence due to new construction, need to be known. This information generally can be collected from the consolidation tests on undisturbed samples collected from different stratum at suitable depths. Generally huge cost and time are required for such testing. Farther more any disturbance, during collection of soil sample, preparation of sample and disturbance during transportation of sample from field to laboratory will affect the values of these properties.

Further it is becoming useful now a day to check correctness of reported results from soil exploration agencies, using available correlations reported by different researchers in geotechnical engineering. Further in most of the civil engineering projects for highways, airways or railways or landscape engineering projects quality control for construction can be made more quickly at the lesser cost by using correlations. Thus, need for correlation study for predicting different engineering properties of soil on the basis of results of simple test requiring low cost, time, expertise and equipment on representative soil samples are becoming popular and gaining importance. A large number of correlations for compression index (C_c) are available. In this paper attempt has been made to check the efficacy of such correlation and to suggest a more reliable correlation for adoption in practice at sites on Gangetic Alluvial soils around Kolkata in West Bengal.

II. LITERATURE REVIEW

Large number of correlations for compression index (C_c) from different simple properties of cohesive soils had been presented by various researchers over last eight decades. Such correlations relate compression index (C_c) with properties like liquid limit (LL), initial void ratio (e_o), void ratio at liquid limit (e_L), specific gravity (G_S), natural moisture content (w_n) and plasticity index (PI) of cohesive soil. The available correlations maybe broadly classified into correlations related to (i) Liquid limit (LL), (ii) Void ratio at liquid limit (e_L), (iii) Liquid limit (LL) and Initial void ratio (e_o), (iv) Initial void ratio (e_o), (v) Natural moisture content (w_n), (vi) Plasticity index (PI) respectively. Accordingly such correlations are tabulated in Tables-1 are given below.

Table-1

SL. No	Correlation	Applicability	Reference
A.Existing Correlations of Compression Index (C_c) related to Liquid Limit (LL):			
1	$C_c = 0.007$ (LL – 10)	Remolded cohesive soils	Skempton(1944)
2	$C_c = 0.01$ (LL–12)	Osaka alluvial clays	Murayama et al. (1958)
3	$C_C = 0.013$ (LL–13.5)	All clays	Yamagutshi (1959)
4	$C_c = 0.013$ LL	Ariake clay	Kyushu Branch of JSSMFE (1959)
5	$C_c = 0.014$ (LL–20)	Ishikari clay	Taniguchi et al. (1960)
6	$C_c = 0.0046$ (LL–9)	Brazilian clays	Cozzolino (1961)
7	$C_c = 0.004$ (LL–10)	Rumoi clay	Taniguchi (1962)
8	$C_c = 0.017$ (LL–20)	All clays	Shouka (1964)
9	$C_c = 0.009$(LL – 10)	Undisturbed clay of medium or low sensitivity	Terzaghi and Peck (1967)
10	$C_c = 0.006$ (LL–9)	All clays with LL< 100%	Azzouz et al. (1976)
11	$C_c = 0.015$ (LL-19)	All clays	Ogawa (1978)
12	$C_c =$ (LL–13)/109	Soil (with LL<100%)	Mayne (1980)
13	$C_c = 0.0063$ (LL–10)	Egyptian clay	Abdrabbo and Mahmoud (1990)
14	$C_c = 0.01$ LL–0.063	Natural soils (cohesive)	Hirata et al. (1990)
B.Existing Correlations of Compression Index (C_c) related to Initial Void Ratio at Liquid Limit (e_L):			
15	$C_c = 0.2237\ e_L$	Various clays	Nagaraj and Murthy (1983)
16	$C_c = 0.2343\ e_L$	All remoulded normally consolidated clays	Nagaraj et al. (1985)
17	$C_c = 0.274\ e_L$	Various clays	Nagaraj et al. (1995)
C.Existing Correlations of Compression Index (C_c) related to Liquid Limit (LL) and Initial Void Ratio (e_o):			
18	$C_c = 1.21 + 0.0072$ (LL - 95) + 0.53 (e_0 -1.87)	Soft clay and silts	Cozzolino (1961)
19	$C_c = 0.256 + 0.00106$ (LL - 65) + 0.32(e_0 - 0.84)	Heavy and medium clay and silts	Cozzolino (1961)
20	$C_c = 0.21\ e_o + 0.00341$ LL - 0.07	Various clays	Sengupta (1974)
21	$C_c = 0.37$ (e_0 + 0.003 LL + 0.004)	Various clays	Bowels (1982)

D.Existing Correlations of Compression Index (C_c) related to Initial Void Ratio (e_o):			
22	$C_c = 0.54 (e_o - 0.35)$	Undisturbed clays	Nishida (1956)
23	$C_c = 0.29 (e_o - 0.027)$	Inorganic silty clay	Hough (1957)
24	$C_c = 0.4049 (e_o - 0.3216)$	Cohesive soil,silt,cla,silty clay and inorganic soil	Hough (1957)
25	$C_c = 0.35 (e_o - 0.5)$	Organic soils	Hough (1957)
26	$C_c = 0.43 (e_o - 0.25)$	Brazilian clay	Cozzolino(1961)
27	$C_c = 0.246 + 0.43 (e_o - 0.25)$	Motley clays of Sao Paulo, Brazil	Cozzolino (1961)
28	$C_c = 1.21 + 1.055 (e_o - 1.87)$	Low lands of Santos, Brazil	Cozzolino (1961)
29	$C_c = 0.50 (e_o - 0.5)$	Undisturbed clays	Serajuddin (1969)
30	$C_c = 0.75 (e_o - 0.5)$	Low plasticity soil	Sowers (1970)
31	$C_c = 0.4 (e_o - 0.25)$	Clays , USA and Greece	Azzouz (1976)
32	$C_c = 0.30 (e_o - 0.27)$	America's clay	Rendon- Herrero (1980)
33	$C_c = 0.33 (e_o - 0.35)$	Undisturbed Clays	Amin et al.(1987)
34	$C_c = 0.208 e_o + 0.0083$	Chicago clays	Bowles (1989)
35	$C_c = 0.156 e_o + 0.0107$	All clays, (Moderately Over consolidated)	Bowles (1989)
36	$C_c = 0.42 (e_o - 0.5)$	Egyptian clays with 0.6< e0<2.0.	Abdrabbo and Mahmoud (1990)
37	$C_c = n_0/(371.747 - 4.275 n_o)$ $= e_0/(371.747 + 367.472 e_0)$	Various clays	Park and Koumoto (2004)
E.Existing Correlations of Compression Index (C_c) related to Natural Moisture Content (w_n).			
38	$C_c = 0.0102 (w_n - 9.15)$	Cohesive soil,silt,cla,silty clay and inorganic soil	Hough (1957)
39	$C_c = 0.01 (w_n - 5)$	All type of clay	Azzouz et al. (1976)
40	$C_c = 0.01 w_n$	All type of clay	Koppula (1981)
41	$C_c = 0.01(w_n - 7.549)$	All type of clay	Herrero (1983)
42	$C_c = 0.0102 (w_n - 9.15)$	Alluvial clay and silt in Bangladesh	Serajjudin (1987)
43	$C_c = 0.0115 w_n$	Organic silt and clays	Bowles (1989)
44	$C_c = 0.0066 w_n$	Egyptian clays with 20% < wn < 140%.	Abdrabbo and Mahmoud (1990)
45	$C_c = 0.0103 w_n$	Various clays	Nagaraj (2001)
F.Existing Correlations of Compression Index (C_c) related to Plasticity Index (PI):			
46	$C_c = 0.02 + 0.014 PI$	North Atlantic clay	Nacci et al.(1975)
47	$C_c = 0.5 PI G_S$	Various Clays	Wroth and Wood (1978)
48	$C_c = 1.325 PI$	Remoulding clays	Wroth et al. (1978)
49	$C_c = 1.325 PI$	Remoulding clays	Koppula (1981)
50	$C_c = 0.014 (PI + 3.6)$	Remoulding clays	Sridharan and Nagaraj (2000)
51	$C_c = 0.015 PI - 0.0198$	Various Clays	Nath and Dedalal (2004)
52	$C_c = 0.0082 PI + 0.0475$	Alluvial Soil	Jain et al. (2015)

III. CHECKING OF THE VALIDITY OF REFERRED CORRELATION FOR COMPRESSION INDEX

Fifty two correlations for compression index (C_c) of cohesive soils with different simple soil property have been presented over last eight decades (Table -1). For practicing foundation engineer, it becomes imperative to identify this suitable one for which the predicted value from the correlation tallies with the experimental value with reasonable accuracy. For this purpose a program was under taken to check the validation of presented correlations with determined value of C_c from consolidation test on undisturbed alluvial soil on either side of river Hooghly around Kolkata, West Bengal, India. For this purpose large no of experimental test data from soil exploration for different projects in the area were collected from different sources. A summary of collected experimental test result are provide in table-2.

Table-2

LL (%)	PI (%)	Wn (%)	e_0	C_c	LL (%)	PI (%)	Wn (%)	e_0	C_c	References
49	25	29.5	0.8	0.21	74.5	48	32	0.6	0.19	[38]
40	19	25.8	0.64	0.19	52.5	26.5	30	1	0.1	[38]
35.5	14	34	0.75	0.22	68.5	39.5	33	0.5	0.12	[38]
60.5	29	41.5	0.95	0.36	56	31	30	0.85	0.3	[38]
82	57	38	1.01	0.18	68	44	26.5	0.71	0.25	[38]
51.5	27	31	0.74	0.21	42	18	30	0.73	0.25	[38]
52	20	36	3.5	2.6	49.5	26	30.5	0.73	0.22	[38]
43	20	36.5	0.81	0.26	44.5	20.5	28	0.77	0.2	[38]
37.5	18	34.5	0.68	0.19	63.5	36	46	0.96	0.4	[38]
43	19	32	0.86	0.25	47	24.5	31	0.8	0.2	[38]
48.5	23.5	26.5	0.72	0.18	34.5	10	32	0.77	0.16	[38]
33.5	11	27	0.82	0.15	37.5	18	18.5	1.12	0.3	[38]
69	44	26	0.7	0.22	37.5	18	28.5	0.45	0.08	[38]
48	24.5	28.5	0.7	0.12	43	18	30	0.73	0.25	[38]
49	25	42.6	0.96	0.3	39	16	36	0.51	0.21	[39]
54	27	40.2	0.62	0.2	55	31	36.4	0.87	0.3	[39]
52	25	38.5	0.65	0.19	54	32	43.5	1.15	0.29	[39]
49	23	38.8	0.59	0.22	66	42	35.7	0.75	0.23	[39]
51	25	42.4	0.66	0.23	52	29	37.8	0.71	0.43	[39]
42	17	35.2	0.51	0.16	36	15	35.4	0.65	0.39	[39]
35	13	33.5	0.49	0.18	50	25	46	1.22	0.45	[39]
53	26	39.5	0.74	0.34	54	26	35.6	0.85	0.33	[39]
50	24	36.5	0.63	0.29	61	29	35.6	0.96	0.41	[39]
49	24	34.5	0.56	0.28	42	18	33.2	0.86	0.36	[39]
39	15	26.9	0.71	0.15	35	14	32.2	0.73	0.38	[39]
42	14	33.9	0.68	0.18	52	26	30.4	0.81	0.23	[39]
37	14	34.4	0.65	0.19	55	28	32.2	0.75	0.2	[39]
35	14	33.5	0.61	0.18	42	18	37.5	0.66	0.21	[39]
43	27	35.5	0.6	0.23	51	24	30.5	0.82	0.26	[39]
46	29	36.2	0.66	0.21	48	25	29.9	0.74	0.28	[39]
41	26	32.8	0.7	0.22	48	23	30.1	0.63	0.21	[39]
39	25	33	0.58	0.22	50	24	33.2	0.67	0.23	[39]
43	16	32.6	0.52	0.28	44	20	32.2	0.58	0.19	[39]
42	14	33.5	0.55	0.24	34	16	29.6	0.79	0.29	[39]
40	11	34.2	0.59	0.17	53	27	35.4	0.78	0.29	[39]
41	12	34.3	0.56	0.29	42	17	29.9	0.75	0.21	[39]
41	12	33.5	0.55	0.29	50	24	32.5	0.74	0.22	[39]
52	26	35.2	0.84	0.33	48	25	36.5	0.8	0.33	[39]
43	16	36.4	0.61	0.27	62	32	42.5	0.82	0.32	[39]
42	16	34.2	0.62	0.29	34	13	32.4	0.9	0.43	[39]
34	11	31.4	0.83	0.24	37	15	24.5	0.52	0.1	[39]
43	16	35.3	0.67	0.28	40	16	23.9	0.49	0.1	[39]
39	14	33.5	0.89	0.33	38	15	24.2	0.52	0.1	[39]
39	13	32.4	0.69	0.26	35	11	23.8	0.48	0.1	[39]
43	16	34.2	0.57	0.19	33	13	23.5	0.52	0.1	[39]
38	14	31	0.83	0.28	34	12	24.6	0.53	0.1	[39]
44	16	33.5	0.59	0.28	33	15	23.8	0.49	0.1	[39]
42	17	35.5	0.95	0.3	32	12	24.5	0.48	0.1	[39]
31	12	30.3	0.55	0.22	45	22	24.6	0.53	0.1	[39]
36	14	26.7	0.72	0.36	41	20	24.9	0.51	0.1	[39]
39	15	34.3	0.64	0.36	35	16	23.8	0.52	0.1	[39]
63	40	29.3	0.55	0.27	32	11	24.1	0.51	0.1	[39]
42	18	36.3	0.97	0.36	32	12	24.5	0.49	0.1	[39]
39	16	34.5	0.85	0.33	43	22	24.6	0.52	0.1	[39]
50	24	34.4	0.74	0.32	38	15	24.4	0.51	0.1	[39]
51	25	32.6	0.69	0.26	35	14	24.3	0.53	0.1	[39]
48	23	33.3	0.58	0.23	34	14	23.6	0.49	0.1	[39]
53	25	34.3	0.66	0.23	37	15	28.5	0.53	0.1	[39]
63	32	55.7	0.84	0.38	35	14	25.6	0.51	0.1	[39]
56	30	45.6	1.05	0.26	32	11	23.9	0.52	0.1	[39]
32	11	23.7	0.48	0.07	32	13	25.5	0.73	0.1	[39]
33	12	24.3	0.53	0.08	46	23	32.1	0.91	0.2	[39]
30	10	23.9	0.48	0.07	46	13	44	1.3	0.3	[39]
45	12	41	1.24	0.27	55	31	28	0.81	0.2	[39]
67	28	49	1.4	0.26	32	13	25	0.71	0.1	[39]
45	12	43	1.25	0.27	48	25	30.2	0.91	0.2	[39]
69	19	54	1.43	0.24	46	24	28	0.82	0.2	[39]
44	16	29.7	0.91	0.18	35	6	30.3	0.9	0.2	[39]
46	24	33.2	0.95	0.2	35	5	31.5	0.94	0.2	[39]
70	28	52	1.4	0.4	38	9	32	0.91	0.2	[39]
42	19	29.5	0.83	0.16	34	13	30	0.92	0.2	[39]
33	14	27	0.75	0.13	41	12	32.8	0.95	0.2	[39]
40	17	32.2	0.93	0.18	40	12	32	0.93	0.2	[39]
50	27	33	0.93	0.2	42	20	28	0.81	0.2	[39]
60	29	27.6	0.82	0.17	40	17	29	0.88	0.2	[39]
33	13	25.6	0.71	0.13	35	6	31.5	0.94	0.2	[39]
47	25	30.2	0.87	0.17	50	25	27.4	0.8	0.1	[39]
45	12	41	1.29	0.28	41	13	31	0.94	0.2	[39]
32	13	26.6	0.73	0.14	61	35	31	0.97	0.2	[39]
44	20	31	0.91	0.19	45	21	25	0.77	0.1	[39]
46	13	41	1.3	0.27	42	19	25	0.7	0.1	[39]
49	26	29.2	0.85	0.17	41	12	31	0.94	0.2	[39]
52	25	31.45	0.51	0.23	42	16	35.5	0.47	0.2	[40]
39	18	31.9	0.49	0.26	39	15	36.2	0.96	0.27	[40]
51	24	34.5	0.53	0.28	43	16	36	0.49	0.18	[40]

In the first set of correlation for compression index (C_c) attempt is made to predict C_c in terms of liquid limit. Several correlations are available and applicability of each correlation is also noted in table-1 itself. From the collected soil investigation result the experimental value of compression index are plotted against experimental values of liquid limit in fig-1. In the same plot predicted values for compression index are plotted against liquid limit. The given correlations being linear several straight line relations have resulted due to different correlaters. However plotted experimental values of C_c against liquid limit do not follow any of the proposed correlation with reasonable accuracy.

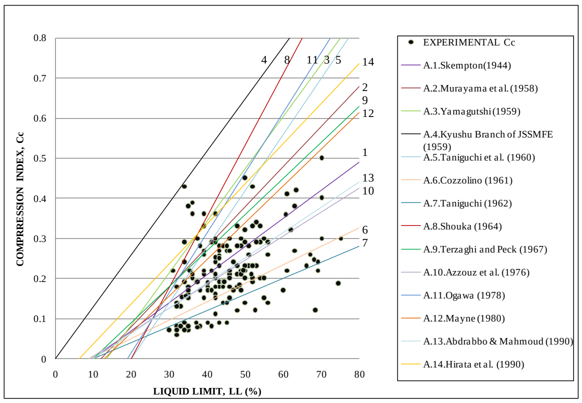

Fig. 1. Compression Index (C_c) versus Liquid Limit (LL).

In the second set of the correlation attempt has been made to predict C_c in terms of initial void ratio at liquid limit (e_L). All the three correlations are linear with varying proportionality. The relationships are plotted in C_c Vs e_L plot in fig-2 generating three straight lines passing through the origin on the same plot. Experimental values of C_c are plotted against noted values of e_L .Examining the fig-2, it is obvious that the available correlations fail to predict the desire value in most of the cases.

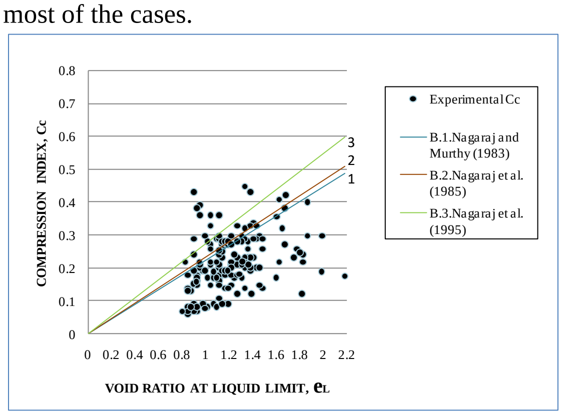

Fig. 2. Compression Index (C_c) versus Void Ratio at Liquid Limit (e_L).

In the third set for correlation prediction for compression index have been presented on the basis of liquid limit (LL) and initial void ratio (e_o) of the soil. Four such correlations have been considered .Predicted value of C_c have been calculated from the prediction using the experimental results of liquid limit and initial void ratio of soil from table -2. These predicted values of C_c have been plotted against reported experimental values of compression index in fig -3. A line through origin having an inclination of 45^0 has also been drown in the same plot. Majority of the plotted points are widely scattered from the 45^0 line indicating non applicability of the proposed prediction.

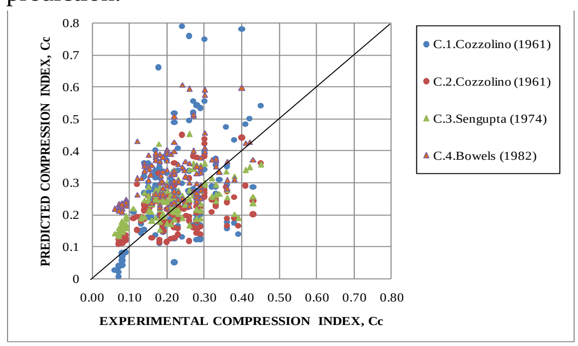

Fig. 3. Comparison of Experimental and Predicted Compression Index (C_c) values.

In the fourth set of the correlations compression index has been correlated with initial void ratio of the soil, with varying linear relation by large number of researchers. From the table -2, different experimental test results of initial void ratio and experimental values of compression index are plotted in fig-4. In the same plot predicted value of compression index from the available prediction are also shown. Examining the fig-4 does not confirm the validity of the most of the predictions.

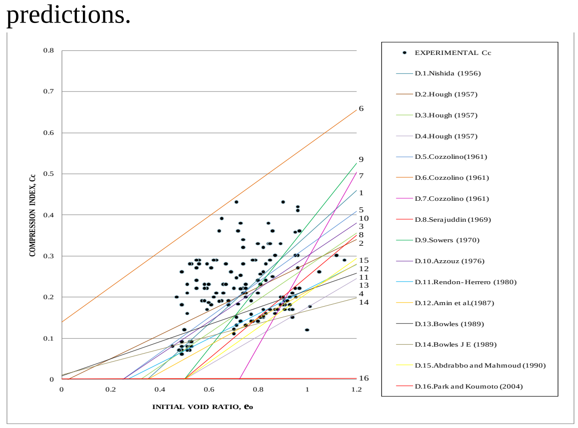

Fig. 4. Compression Index (C_c) versus Initial Void Ratio (e_0).

In the fifth set of correlation of the C_c large numbers of researchers have tried to correlate C_c with natural moisture content (w_n) of the soil with various relationships. In fig-5 experimental values of C_c has been plotted against corresponding natural moisture content. In the same fig the linear relationship given by the correlaters are also drown. The plotted points unfortunately do not show any inclination to follow any linear relation.

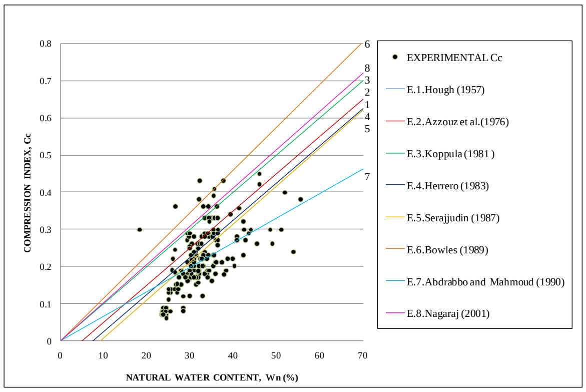

Fig. 5. Compression Index (C_c) versus Natural Water Content (w_n).

In sixth set of correlation C_c several researchers have provided direct linear relationship between compression index and plasticity index. Details of this relation are given in table-1. The experimental values of C_c and corresponding values of PI are chosen from table-2 for various locations around Kolkata in Hooghly river basin and are plotted in fig-6.The plotted pointes however do not show any regular relation between compression index and plasticity index. The correlations available from the set six have also been plotted in the same fig indicated by seven straight lines. None of the correlations can be considered to support the experimental values.

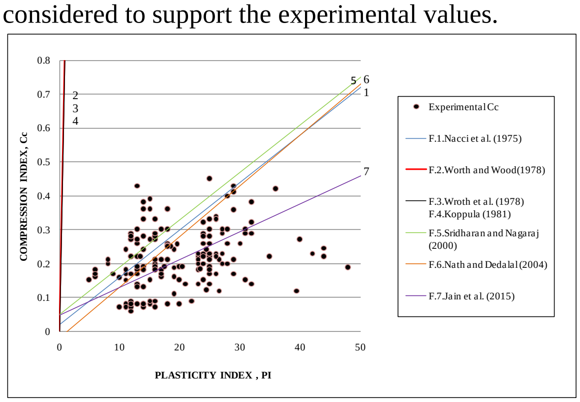

Fig. 6. Compression Index (C_c) versus Plasticity Index (PI)

IV. CONCLUSION

Large numbers of correlations for predicting value of compression index (C_c) of a cohesive soil from its simple properties have been used to estimate value of compression index of alluvial soils on both sides of river Hooghly around Kolkata in Bengal. However for such soil the predicted values from such correlations when compared with experimental values do not compare satisfactorily. The liquid limit and plastic limit of cohesive soil no doubt are of unique value and can be taken to identify the soil and are used for classification of cohesive soils internationally. But engineering properties like Compression index (C_c) of such soil seems not to depend surely on such value. Similar observations were also reported by Satyanarayana and Reddy (2009) who studied for validity of such correlation on marine clay. They concluded that majority of existing correlation based on influencing factor like liquid limit, initial void ratio or natural moisture content are not valid for marine clay.

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