EMPIRICAL CORRELATION BETWEEN COMPRESSION INDEX AND LIQUID LIMIT OF INORGANIC SOILS IN BANGLADESH

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ABSTRACT

The compression index (C_c) is a key parameter for estimating the consolidation settlement of foundations underlain by fine-grained soils. The conventional approach to determining this parameter is to collect undisturbed soil samples and perform the one-dimensional consolidation test in the laboratory. However, as the laboratory one-dimensional consolidation test is time-consuming, researchers worldwide have developed numerous empirical correlations between the compression index and other relevant physical parameters of soils. Among these correlations, predicting the compression index from the liquid limit (LL) of soils is extensively used. This study focused on establishing a correlation between the compression index and the liquid limit values based on laboratory results of 22 inorganic undisturbed soil samples collected from five construction sites in Bangladesh. According to the unified soil classification system, 15 samples were classified as CH, four as CL, and three as ML. The observed soil colors included grey and light brown to brown. The water content, specific gravity, void ratio, liquid limit, plastic limit, and compression index of the soil samples varied within the ranges of 21.24% - 42.14%, 2.62 - 2.77, 0.523 -1.118, 29 - 62, 15 - 27, and 0.112 - 0.59, respectively. A comprehensive regression analysis was performed, which yielded the correlation equation as $C_c = 0.0082 \times (LL - 17)$. This empirical correlation was compared with ten previously published, well-known equations. The empirical relationship proposed in this study was found to lie between the upper and lower boundaries formed by the selected ten equations. Therefore, the developed correlation equation is expected to be beneficial for the professional engineers of Bangladesh to estimate the consolidation settlement of foundations.

Keywords: *Foundation settlement, consolidation test, compression index, liquid limit, empirical correlation.*

1. INTRODUCTION

Soil is a natural mixture of mineral particles produced by rock weathering, blended with organic matter, which contains pore spaces filled with air and water. The physical and mechanical characteristics of the soil play a key role in any design or construction decisions. The design and stability of structures depend highly on properties such as plasticity, compressibility, and soil strength. So, it is crucial to determine these properties to avoid any significant or costly construction errors. However, the properties of the soil need to be determined based on detailed engineering characteristics rather than visual inspections. The reliability of empirical correlations for fine-grained soils in Bangladesh is strongly affected by the quality of undisturbed soil samples and the specific local laboratory testing practices employed (Jabed Omar et al., 2025). Among these properties, two important properties are the Liquid limit (LL), the minimum water content at which a fine-grained soil begins to behave like a viscous liquid and loses its shear strength, and the compression index (C_c), a dimensionless parameter that measures its compressibility, specifically the rate at which its void ratio decreases as effective stress increases during consolidation. LL is a physical property, whereas C_c is a mechanical soil property (Giri, 2019; Hama Ali et al., 2019; Sharma & Bora, 2015).

Among these two, the liquid limit is easy to determine as it is low-cost and straightforward, whereas C_c is difficult to measure and costly. So, many researchers have developed an empirical correlation between these two properties for many years. Like in 1944, Skempton proposed a correlation for remoulded clay: $C_c = 0.007(LL - 10)$. Another correlation has been introduced by Terzaghi and Peck in 1967 for normally consolidated clays, $C_c = 0.009(LL - 10)$. Subsequently, it can be said that the correlation between LL and C_c has historical significance. Previous research has found that C_c also increases with the increase of LL (Ahmed & Agaiby, 2020; Ali & Mohammed, 2025; Alnmr et al., 2024; Hama Ali et al., 2019; Sharma & Bora, 2015; Spagnoli & Shimobe, 2020; Tuc et al., 2025; Zia Ur Rehman et al., 2021). However, geographical location and origin have an impact on the correlation. So, refining these relationships can help produce a globally and regionally precise applicable equation. Although various international correlations were available and validated, there is very limited information on regional-specific models for Bangladeshi soils, and they are affected by depositional environments and mineralogical peculiarities. This paper addresses this gap by developing and proving a localised correlation.

2. MATERIALS AND METHODS

2.1 Sample collection

Soils collected from five different sites inside Bangladesh were used to establish the empirical correlation between the compression index and the liquid limit. The sites are Jashore, Mohakhali, Mailbag, Rampura, and Savar. About 22 inorganic undisturbed soil samples, each collected from a different borehole, were used. The samples were collected from various depths ranging from 2.13 m to 37m. For collecting the undisturbed soil, 76mm external diameter thin-walled Shelby tubes were used, and sealing wax was applied to retain the original moisture content, following the procedure of ASTM D1587.

2.2 Laboratory testing

Different colours were observed among the samples, like grey, light brown, brown, etc. Sieve analysis and hydrometer test were conducted to determine grain size distribution. Then, using this and the Atterberg limit test, the obtained soils were classified as per the Unified Soil Classification System (USCS), as designated in ASTM D2487, from which CH (high plastic clay), CL (low plastic clay), and ML (low plastic silt) were found. The sieve analysis and hydrometer test were done according to ASTM D422 and ASTM D7928. Between the one-point or Casagrande operator method to determine the liquid limit, the Casagrande method was used here. Most of the time, five points were taken to determine the liquid limit for higher accuracy. The test was conducted following ASTM D4318. For one-dimensional consolidation, specimens were trimmed to 62.5 mm in diameter and 25 mm in thickness. In this test, vertical stress was applied on the specimens incrementally at 5, 13, 25, 50, 100, 200, 400, and 800 kPa. Following completion of the loading sequence, the specimens were unloaded to 400, 200, 50, and 10 kPa, and swelling was monitored at each stress decrement. C_c was determined as a slope of the virgin compression line in the graph of void ratio versus the logarithm of applied pressure (e-log p). The entire procedure was done in compliance with ASTM D2435.

3. RESULTS AND DISCUSSION

3.1 Figures and Graphs

The flow parameters that are necessary in the geotechnical engineering of the inorganic soils under study were measured to determine their plasticity and workability. Data points on each of the samples were utilised (using the Casagrandy method) to obtain more accurate values of the liquid limit (LL) and plastic limit (PL). The graphical data provided in Figures 1 and 2 show that the LL of the soil lies between 29 and 62, indicating the variability of the soil in the sampled sites. These values also show the difference in Atterberg limits of soils of Jashore, Mohakhali, Malibbag, Rampura, and Savar due to the mineralogy and clay content differences. The soil behaviour is greatly affected by the depositional environment, as has been seen in the graphical trends. In the case of foundation design and settlement analysis, soil with a high LL value is more flexible and can have a high level of deformation before failure. The flow characteristics are used to categorise soils using the Unified Soil Classification System (USCS), and they form the main inputs in further compressibility and consolidation investigations. There are also samples with significantly high LL values, meaning that the content of clay minerals and soil formation varies, directly influencing the engineering properties and construction suitability. Table 1 and Figure 2 indicate that the values of LL of Rampura soils tend to be higher than those of Savar soils, indicating a higher percentage of fine-grained particles and high potential compressibility.

The determination of soil compressibility parameters is based on the graphical expression of the consolidation characteristics, mainly the curve of the void ratio against the logarithm of adequate pressure (e-log p). This curve is based on the one-dimensional tests of consolidation (oedometer) and represents the behaviour of soil to the gradual loading in a drained state. The relationship between e-log p is usually characterised by a recompression (or overconsolidation) zone at low effective stress and a virgin compression zone at high stress. C_c is represented by the slope of the virgin compression line derived from linear regression analysis and is required to estimate the primary compression settlement in geotechnical engineering design. The representative e-log p curves of Jashore, Mohakhali, Malibbag, Rampura, and Savar soils are shown in Figure 3 and Figure 4. These values demonstrate the differences in the compressibility behaviour of different geological environments in Bangladesh. According to such graphical analyses, the initial void ratio (e_0) of the soils under test is between 0.523 and 1.118, which means that the soils differ in their depositional history, mineralogical composition, and the degree of consolidation. Figure 3 and Figure 4 also underline the variations in the slope of the virgin compression lines between the study sites.

The soils of Malibag and Rampura, located in floodplain deposits of Dhaka, have comparatively higher C_c values, suggesting a higher compressibility by virtue of a higher clay fraction and plasticity. On the other hand, the Jashore and Savar soils are formed by compressed or mixed fluvial deposits, indicating lower compressibility capacity. The entire range of the consolidation outcomes is summarised in Table 1 and includes the parameters of initial void ratio (e_0) and compression index (C_c). The tabulated and graphical findings complement each other to highlight the importance of the soil variability of the region in generating empirical relationships between the compression index (C_c) and the liquid limit (LL) for Bangladeshi inorganic soils. Therefore, these values act as soil analysis mechanisms to interpret compressibility behaviour and empirical confirmation of the suggested C_c-LL correlation models, which link laboratory data with predictive settlement analysis in foundation design applications.

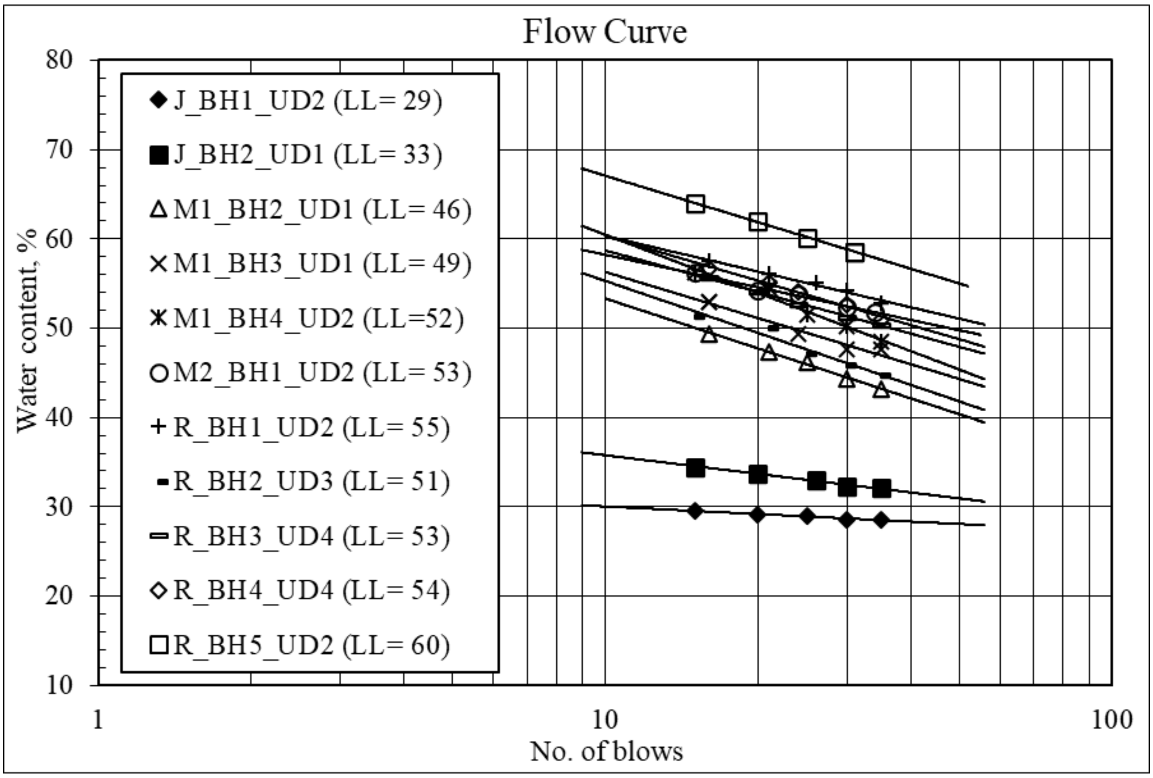

Figure 1: Flow characteristics of Jashore, Mohakhali, Malibagh, and Rampura soils

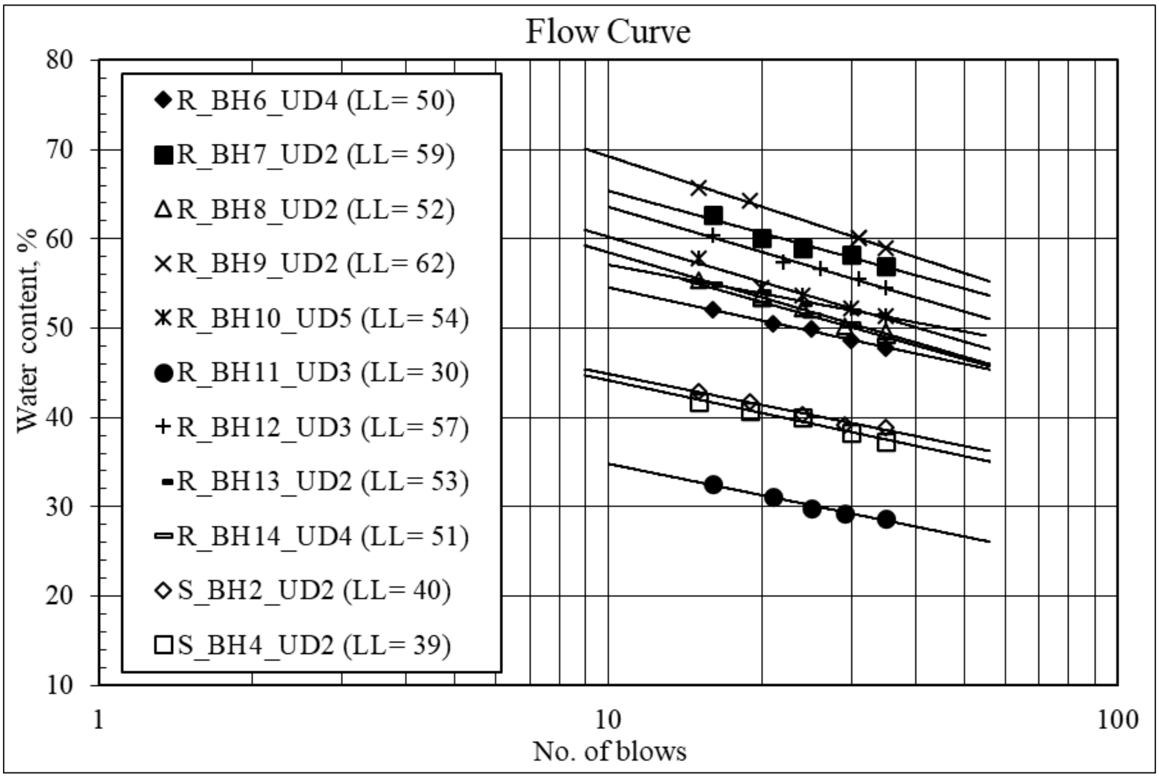

Figure 2: Flow characteristics of Rampura and Saver soils

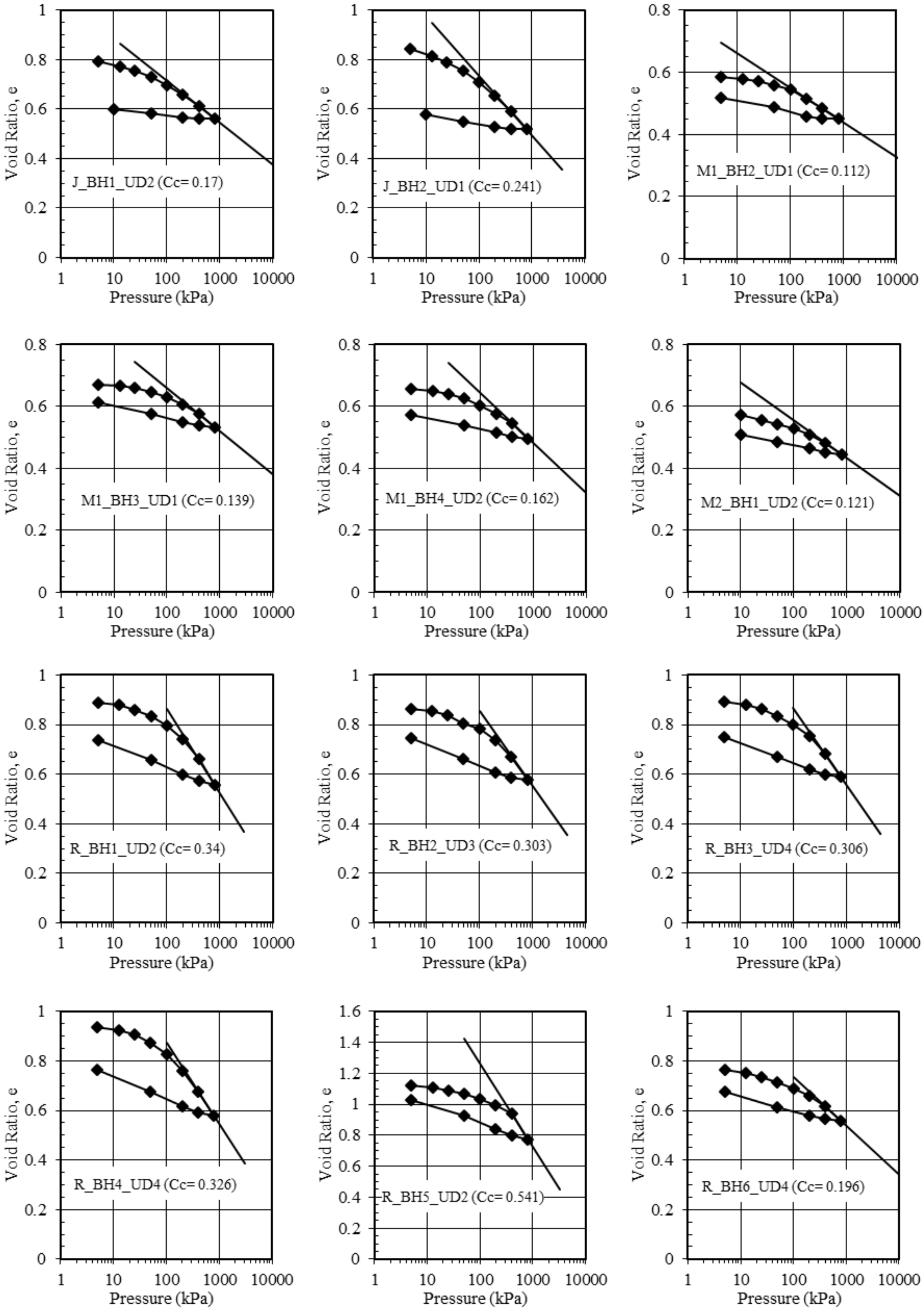

Figure 3: e-log P Curve for consolidation characteristics of Jashore, Malibagh, Mohakhali, and Rampura deposits

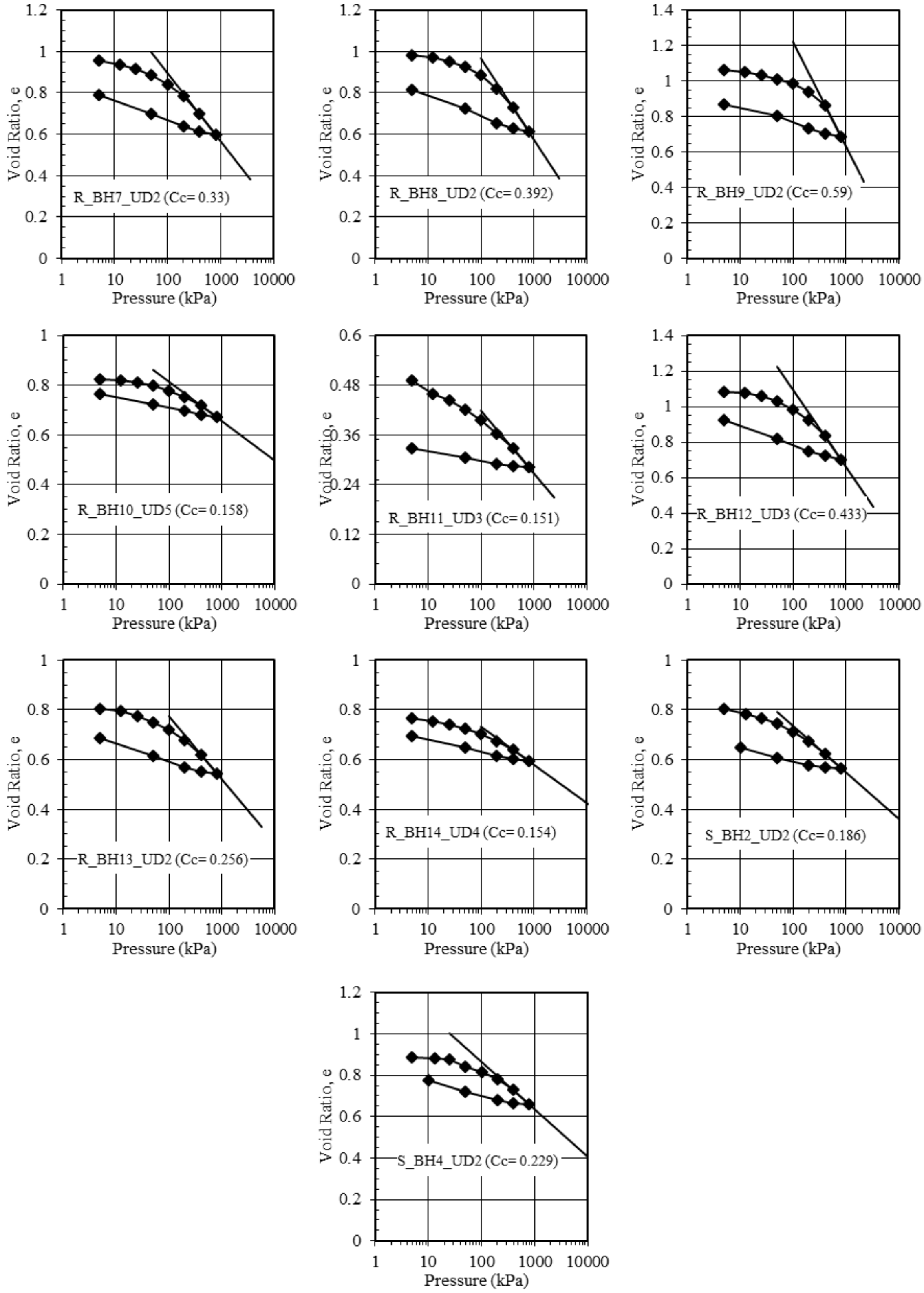

Figure 4: e-log P curve for consolidation characteristics of Rampura and Savar deposits

Table 1: Geotechnical and physical properties of inorganic soil samples

Sl. No.	Sample ID	Depth (m)	Colour	w_n	G_s	e_0	LL	PL	C_c	USCS Classification
1	J_BH1_UD2	3.66-4.15	Light Brown to Grey	25.39	2.68	0.83	29	23	0.17	ML
2	J_BH2_UD1	2.13-2.62	Grey	31.09	2.72	0.89	33	23	0.241	CL
3	M1_BH2_UD1	2.13-2.59	Reddish brown	22.25	2.68	0.589	46	20	0.112	CL
4	M1_BH3_UD1	3.66-4.12	Reddish brown to brown	25.8	2.67	0.679	49	21	0.139	CL
5	M1_BH4_UD2	5.18-5.64	Brown	27.4	2.69	0.688	52	23	0.162	CH
6	M2_BH1_UD2	3.66-4.15	Reddish Brown	21.53	2.68	0.59	53	20	0.121	CH
7	R_BH1_UD2	18.5-19.0	Grey	33.72	2.69	0.915	55	23	0.34	CH
8	R_BH2_UD3	20.0-20.5	Grey	32.3	2.71	0.882	51	21	0.303	CH
9	R_BH3_UD4	24.5-25.0	Grey	33.42	2.68	0.901	53	25	0.306	CH
10	R_BH4_UD4	36.5-37.0	Grey	37.26	2.68	0.969	54	24	0.326	CH
11	R_BH5_UD2	15.5-16.0	Grey	40.66	2.72	1.118	60	24	0.541	CH
12	R_BH6_UD4	32.0-32.5	Light Brown to Brown	30.01	2.67	0.785	50	20	0.196	CH
13	R_BH7_UD2	20.0-20.5	Grey	38.91	2.67	0.952	59	20	0.33	CH
14	R_BH8_UD2	14.0-14.5	Grey	36.73	2.64	0.964	52	21	0.392	CH
15	R_BH9_UD2	17.0-17.5	Grey	40.7	2.66	1.083	62	22	0.59	CH
16	R_BH10_UD5	30.5-31.0	Mixture of Grey & Brown	29.77	2.73	0.832	54	20	0.158	CH
17	R_BH11_UD3	11.0-11.5	Grey	21.24	2.62	0.523	30	15	0.151	CL
18	R_BH12_UD3	18.5-19.0	Grey	42.14	2.64	1.086	57	23	0.433	CH
19	R_BH13_UD2	12.45-13.0	Grey	30.87	2.66	0.819	53	21	0.256	CH
20	R_BH14_UD4	35.0-35.5	Light Brown to Brown	27.23	2.72	0.773	51	25	0.154	CH
21	S_BH2_UD2	9.76-10.24	Grey	28.13	2.75	0.846	40	27	0.186	ML
22	S_BH4_UD2	11.28-11.77	Light Brown	32.33	2.77	0.911	39	27	0.229	ML

Note: w_n = Water content, G_s = Specific gravity, e_0 = Initial void ratio, LL = Liquid limit, PL = Plastic limit, C_c = Compression index.

3.2 Correlation Analysis

The liquid limit and the compression index are generally well-correlated; thus, LL is a useful parameter for estimating soil compressibility in geotechnical engineering applications. C_c determination by oedometer testing is usually expensive, cumbersome, and time-consuming, while the LL is an index property that can be measured easily and quickly, even with disturbed samples. Establishing an empirical correlation between LL and C_c will enable engineers to make quick and reasonably good estimates of compressibility, especially during preliminary design or when resources are limited.

Studies have been conducted in various parts of the world, and all results show that soils with higher liquid limits usually exhibit higher compression index values. Several models involving regression equations for different varieties of fine-grained soils, normally consolidated and remoulded clays, have been developed; most of them indicate a statistically significant linear relationship between these two parameters. However, the strength and form of this correlation vary widely according to the characteristics of soils, depositional environments, and laboratory procedures followed.

Past research findings show a wide variation in the correlation coefficients reported, suggesting that a relationship between C_c-LL cannot be universally applied. Sample type, mineral composition, organic matter content, and testing precision greatly influence soil structure and compressibility. This explains why a single global equation seldom fits all.

Ten earlier correlations from different researchers between 1944 and 1996 have been compared. Table 2 presents the correlations, the type of soil used, and the researcher's identification. A graph of the compression index against the liquid limit is drawn in Figure 5. An upper and lower bound line has been created using the trendlines from these previous researchers' equations. The upper bound is defined by the equations $C_c = LL^{1.673}/2040$ for LL values ranging from 0 to 6.5, and 62.4 to 70, $C_c = 0.008(LL - 5)$ for LL values ranging from 6.5 to 45, and $C_c = 0.01(LL – 13)$ for LL values ranging from 45 to 62.4. The lower bound is formed by the equations $C_c = 0.01(LL – 13)$ for LL values ranging from 0 to 14.29, and $C_c = 0.003(LL - 10)$ for LL values ranging from 14.29 to 70 (United States Department of Defense, 2022). Twenty-two points in this study have been plotted and classified according to their USCS classification: CH, CL, and ML. A trendline is generated from these points, and the resulting equation that represents the correlation is $Cc = 0.0082 \times (LL – 17)$.

Table 2: Correlation used for analysis

Correlation equation	**Soil type**	**Reference**
$C_c = 0.007(LL - 10)$	Remolded clays.	(Skempton & Jones, 1944)
$C_c = 0.0046(LL - 9)$	Clays from Sao Paulo, Brazil	(Cozzolino, 1961)
$C_c = LL^{1.673}/2040$	Hong Kong marine clay	(Lumb & Holt, 1968)
$C_c = 0.0083(LL - 9)$	Remolded clays	(Schofield & Wroth, 1968)
$C_c = 0.003(LL - 10)$	Cohesive soils of the Rhone Alpes and Valley of the Seine River	(Gielly et al., 1969)
$C_c = 0.006(LL - 9)$	Clays for Greece and the USA	(Azzouz et al., 1976)
$C_c = 0.008(LL - 5)$	Dredging material	(Salem & Krizek, 1976)
$C_c = 0.0079(LL - 16)$	Indiana soils	(Lo & Lovell, 1982)
$C_c = 0.01(LL - 13)$	All clays	(USACE, 1990)
$C_c = 0.009(LL - 10)$	Undisturbed clay of sensitivity less than 4.	(Terzaghi et al., 1996)

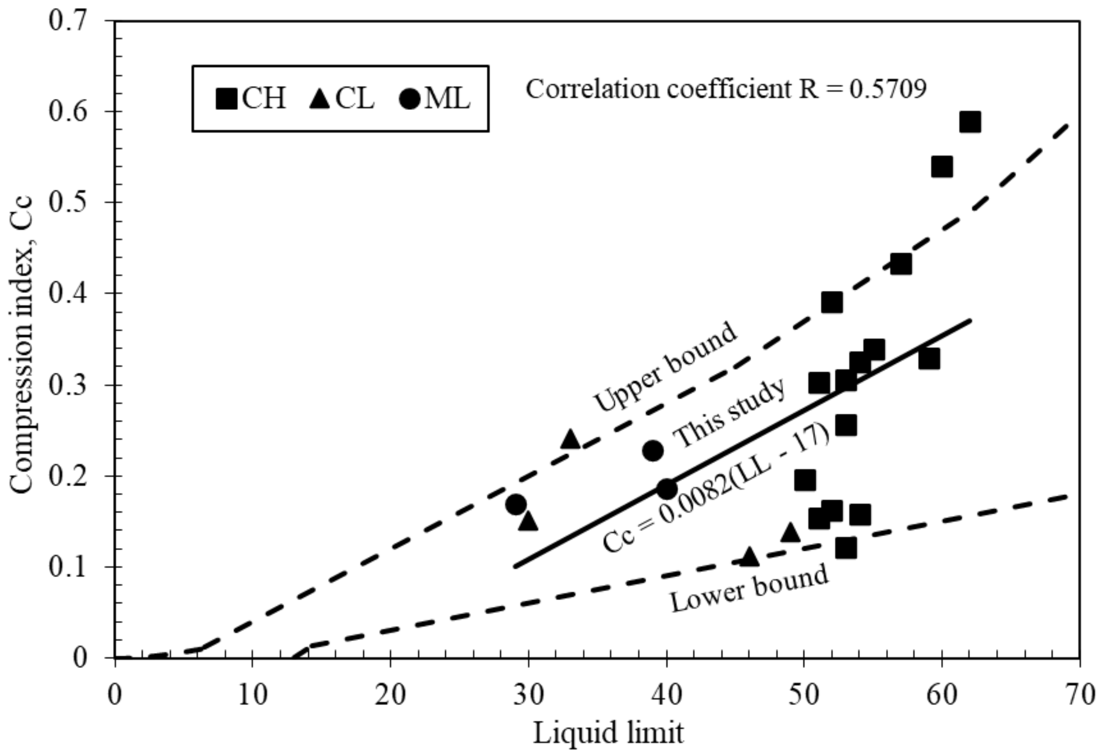

Figure 5: Graphical illustration of the data points relating the soil compression index, C_c, to its liquid limit, LL

4. CONCLUSIONS

An empirical correlation has been developed between (Cc) and (LL) of Bangladeshi inorganic soils. The correlation will estimate the settlement preliminarily and eliminate the necessity of many laboratory tests. Before it is widely adopted, it should be proven to work on other types of soils and areas in Bangladesh. Critical projects still require detailed site investigations. Correlations between Cc and LL are a fast and cheap way of estimating soil compressibility; their application should be done with engineering discretion. It is also recommended that such correlations be checked using locally obtained data or elaborated statistical modelling to enhance their reliability. The empirical correlations can also help engineers make estimations at a low cost and within a brief time. Nevertheless, they do not override the thorough soil exploration and testing during foundation design.

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DECLARATION OF USE OF AI

The authors used AI-based tools, such as Grammarly and ChatGPT to help in spelling, grammar, and sentence clarity. There was no AI tool that was used to produce new ideas, data, analyses, or interpretations. The authors are the only ones who can be held responsible in all intellectual content, arguments, and conclusions. Using AI tools did not affect the scientificity or originality of this piece of work.

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