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RESEARCH ARTICLE

Assessment of Consolidation Coefficient and Index Properties Relation of Erbil Governorate Fine Soils

Zina Mikhael Dawood*

Civil Engineering Department, Erbil Technical Engineering college, Erbil Polytechnic University EPU, Erbil, Kurdistan Region, Iraq

***Corresponding author:**

Zina Mikhael Dawood,
Civil Engineering Department,
Technical Engineering College,
Erbil Polytechnic University, EPU.
Erbil, Kurdistan Region, Iraq
E-mail:
zina.dawood@epu.edu.iq

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ABSTRACT

Correlating geotechnical characteristics based on index properties has been attempted in many regions worldwide. However, no previous studies have examined the soil compressibility behavior of Erbil soil to determine the most suitable soil index property for correlating with compressibility parameters. The investigation addressed this gap by selecting and testing ten fine-grained soil samples from five locations within Erbil city, Iraq, at two different depths: 4-5m and 8-9m. These depths hold significance for future planning of shallow and deep foundations. The study encompassed several soil experimental tests, including moisture content, dry unit weight, void ratio, consistency limits, and conventional consolidation tests. Through correlation analysis, an index property was identified as a predictor for the consolidation coefficient. For the shallow and deep depths, the consolidation coefficients ranged from 4.74-5.98 m^2/yr and 4.62-6.79 m^2/yr, respectively. Consequently, a new equation can be derived to estimate the coefficient of consolidation based on the liquid limit test, thus obviating the need for the conventional consolidation test. The resulting proposed equation is anticipated to assist engineers in estimating the consolidation coefficient for site investigation and designing shallow and deep foundations in fine soils.

Key Words: **Consolidation Coefficient, soil index properties, experimental investigations, Liquid limit and parametric study.**

1-INTRODUCTION

Before constructing any structure, features like geotechnical and site investigation need to be well considered in foundation design issues to achieve a safe environment. One of the main parameters that could be assessed in the foundation design is the consolidation coefficient. Also, the coefficient is measured based on undisturbed soil samples that can be examined in the laboratory. However, the consolidation tests require a specific technique and the test procedure is time-consuming. It is believed that it is better to assess the consolidation coefficient based on some index soil properties; that is relatively inexpensive and easy to apply, since they do not require much time and qualified equipped actions (Solanki, Desai and Desai, 2010; Sharma and Bora, 2015; Jayalekshmi & Elamathi, 2020; Look, 2023). The soil characteristics are including moisture content, void ratio, dry unit weight, and consistency limits. Many researchers predicted the consolidation coefficients from some index properties using soil samples throughout the world. For example, Sridharan and Nagaraj (2004) tested ten remolded soil samples to obtain the consolidation coefficient c_v. The results were then incorporated with the soil characteristics like plasticity and shrinkage indexes and liquid limit. Based on the experimental results, initially, it has been proposed that a better correlation between the consolidation coefficients and the shrinkage index. However, due to the absence of the shrinkage index in the routine testing, the correlation between the consolidation coefficient and the plasticity index was then recommended (Sridharan and Nagaraj, 2004). Solanki, Desai, and Desai (2008) calculated the consolidation coefficient and index parameters for a normally consolidated clay. The parameters include plastic limits, void ratio, water content, dry unit weight, liquid limit and consolidation parameters. The study is conducted on statistical analysis to determine a suitable correlation for estimating the consolidation response. It was concluded that the best correlation with the consolidation parameter is the soil plasticity compared with the mentioned soil parameters. On the other hand, Sharma and Bora (2015) tested seventeen normally-consolidated saturated fine-grained soils to investigate the relation between the consolidation behavior and Atterberg

Limits. From the multi-analysis of the tested data, it was shown that both the specific gravity and plasticity index of soil have an exclusive function of compression index; similar findings by Wroth and Wood (1978); Carrier (1985) and Solanki (2009). Furthermore, Ng, Chew, and Lazim (2018) experienced five cohesive samples using a one-dimensional consolidation test. It was established that the consolidation coefficient was satisfactory interrelated with both plastic limit and plasticity index, while the compression index was best correlated with the liquid limit. Devi, Devi, Prasad, and Raju (2015) tested five clayey samples to correlate the variation in the values of the consolidation coefficient and the soil index features. It was indicated that the consolidation coefficient records a well corresponding to the soil liquid limit. On the same matter, Solanki et.al. (2008) collected disturbed and undisturbed samples in India at a great depth of 4 m and 8 m. The samples were tested and analyzed based on index and consolidation properties relationships. Several empirical correlations were involved in the analysis to obtain appropriate relationships. It was concluded that the best relation was conducted by the relation between the consolidation coefficient with the liquid limit. This conclusion was agreed by many researchers like (Al-Tae'e & Al-Ameri, 2011; Soibam et. al., 2015 and Devi et. al., 2015). A summary of the main findings by many researchers is listed through Table 1. The typical equation gives the best correlation with the consolidation response. To apply this issue to Erbil soil, a set of samples was collected from five locations throughout Erbil Governorate and associated to find the best correlation between the consolidation coefficient and index properties.

2- MATERIALS AND METHODS

Ten undisturbed fine soils were selected throughout Erbil Governorate from five locations and mapped in Figure 1; Location 1 in Gulan street, Location 2 in Zanyari district, Location 3 in 150 m road Kore city, Location 4 in Ankawa, and Location 5 in 120 m road Roshanbiry. Shallow and deep depths were deliberated for each location; a depth of 4-5 m was taken for the shallow and a depth of 8-9 m was taken for the deep. The shallow and deep depths symbolized the purpose of the future design of shallow and deep foundations, respectively.

A set of element experiments have been made to test the index features including moisture content, soil classification, specific gravity, and consistency index. Besides that, the estimation of the consolidation parameters including consolidation coefficient (c_v), compression index (C_c), rebound index (C_r), pre-consolidation pressure (Pc), and initial void ratio (eo) were also taken into account. Empirical correlations are judged and developed to assess the consolidation coefficient in particular with the soil index properties. Nevertheless, the other calculated consolidation parameters are unconsidered in the analysis, this is because the study focuses on the assessment of the consolidation coefficient regarding to the index properties. The coefficient of consolidation is calculated according to Taylor′s square root of Time Fitting method. The water content and the specific gravity are calculated according to ASTM D2216 and ASTM D854-14, respectively. The liquid and plastic limits are according to ASTM D4318-10. The compressibility test is implemented according to ASTM D-2435-11.

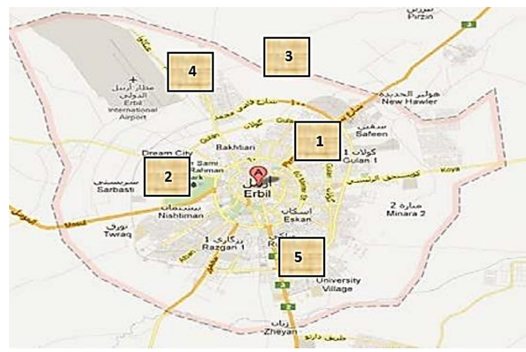

Figure 1: Soil samples location map

3- RESULTS AND DISCUSSIONS

The summary of the soil properties is given through Table 2 and Table 3 at two different depths; 4-5 m and 8-9 m. According to the Unified Soil Classification System (USCS), the soil is considered as a low plasticity clay for the most locations and normal consolidated clay. The ranges of each soil parameter for the samples are given in the same tables. Table 2 and Table 3 show the soil features based on the element laboratory testing results at 4-5 m depth and 8-9 m depth, respectively. It can be seen that water content is very low which is a range of 16-18 % for the depths of 4 m and 8m. This is confidently due to the low level of the water ground surface for all study areas. The liquid limit in the range of 42-49 % and 39-43 % for the 4 m and 8 m depths, respectively. The specific gravity is nearly in the range of 2.66 to 2.70 in which the soil dry unit weight is in the range of 16-17 kN/m3 for both depths. The Liquid limit LL of the five shallow samples ranges from 42-49 % with PL and from 22-27 %. Whereas, the LL ranges from 39-54 % with PL ranges from 21-25 %, respectively for the five deep samples (see Tables 2 and 3). The soil is considered as a low plasticity clay with a plasticity index of 19 to 25% and 18 to 29 % for the 4-5 m and 8-9 m depths, respectively. The same conclusion has been drawn by Katel, Upreti and Pokharel (1996) and

Solanki et. al. (2008). In connection with the consolidation parameters, the c_v is in the range of 4.14-5.98 m^2/yr and 4.62-6.79 m^2/yr for both 4 m and 8 m depths, respectively. In contrast, the range of the consolidation coefficients is hard to be verified due to the lack of soil consolidation data available for Erbil city. In the same matter, the C_c and Cr are nearly in the range of 0.14-0.17 and 0.022-0.031, respectively (see Tables 2 and 3).

To compare the c_v results between the 4m and 8m depth, it is clear to see that c_v values increase with the increase of the depth from 4 m to 8m in which c_v is considered as depth-dependent as investigated by Zhu and Yin, 2012, and Awad, Aldaood and Alkiki, 2022). Finally, the range of the Pre-consolidation pressure, Pc is 180-225 kN/m^2 and 180-250 kN/m^2 for the depth of 4-5 m and the depth of 8-9 m, respectively.

Table 1: Typical equations proposed by some researchers

References	Typical equation	Soil Samples
Sridharan and Nagaraj (2004)	$c_v = 3/(100\ SI^{3.54})$ $(\mathrm{m}^2/\mathrm{s})$	Remolded soil
Solanki et. al. (2008)	$c_v = 7.75\ PI^{-3.102}$ $(\mathrm{cm}^2/\mathrm{s})$	Normally Consolidated
Solanki (2011)	$c_v = 10^8\ LL^{-6.7591}$ $(\mathrm{cm}^2/\mathrm{s})$	alluvial deposits
Al-Tae'e and Al-Ameri (2011)	$c_v = 4258\ LL^{-1.75}$ $(\mathrm{m}^2/\mathrm{s})$	undisturbed silty clay
Devi et. al. (2015)	$c_v = -4 \times 10^{-9} LL + 4 \times 10^{-7}$ $(\mathrm{m}^2/\mathrm{s})$	Clayey soil
Soibam et al. (2015)	$c_v = 4 \times 10^{-7} - 4 \times 10^{9}\ LL$ $(\mathrm{m}^2/\mathrm{s})$	Soft clays
Jadhav (2016)	$c_v = 128.7/3.54\ SI + 0.0002$ $(\mathrm{cm}^2/\mathrm{s})$	Clayey soil
Ng, Chew and Lazim, (2018)	$c_v = 0.451 + 0.011\ LL - 0.036\ PI$ $(\mathrm{m}^2/\mathrm{yr})$	Cohesive soil

c_v: Consolidation coefficient, SI: Shrinkage Index, PI: Plasticity Index, LL: Liquid Limit.

Table 2: Summary of the soil properties results at a depth of 4-5 m

Soil Properties / **Location**	1	2	3	4	5	Range
Water content, w_c (%)	18.1	17.7	18.4	16.9	17.4	16.9-18.4
Specific Gravity, G_s	2.68	2.69	2.65	2.68	2.66	2.65-2.69
Dry unit weight (kN/m^3)	16.6	17.4	16.9	16.4	17.2	16.4-17.4
Liquid Limit, LL (%)	47	49	43	48	42	42-49
Plastic Limit, PL (%)	25	24	24	27	22	22-27
Plasticity Index, PI (%)	22	25	19	21	20	19-25
Unified Soil classification system (ASTM)	SC	CL	CL	CL	CL	CL
Compression Index, C_c	0.15	0.17	0.16	0.15	0.14	0.14-0.17
Rebound Index, C_r	0.03	0.028	0.031	0.029	0.030	0.028-0.031
Consolidation Coefficient, c_v (m^2/yr)	5.32	4.74	5.87	4.97	5.98	4.74-5.98
Initial Void Ratio, e_o	0.61	0.56	0.57	0.62	0.60	0.56-0.62
Pre-consolidation pressure, P_c (kN/m^2)	190	225	180	185	205	180-225

Table 3: Summary of the soil properties results at a depth of 8-9 m

Soil Properties \ Location	1	2	3	4	5	Range
Water content, w_c (%)	17.8	18.6	16.3	18.3	17.9	16.3-18.6
Specific Gravity, G_s	2.71	2.71	2.65	2.68	2.66	2.66-2.71
Dry unit weight (kN/m^3)	16.8	17.1	16.9	16.4	17.4	16.4-17.4
Liquid Limit, LL (%)	42	54	39	46	48	39-54
Plastic Limit, PL (%)	23	25	21	24	25	21-25
Plasticity Index, PI (%)	19	29	18	22	23	18-29
Unified Soil classification system (ASTM)	CL	CH	CL	CL	CL	CL
Compression Index, C_c	0.14	0.14	0.16	0.15	0.14	0.14-0.16
Rebound Index, C_r	0.027	0.022	0.031	0.029	0.030	0.022-0.031
Consolidation Coefficient, c_v (m^2/yr)	6.33	4.62	6.79	5.22	4.87	4.62-6.79
Initial Void Ratio, e_o	0.53	0.55	0.57	0.61	0.60	0.53-0.61
Pre-consolidation pressure, P_c (kN/m^2)	210	250	180	190	205	180-250

4- ANALYTICAL ANALYSIS

A preliminary analysis using Excel sheets to choose an appropriate correlation between the consolidation coefficient and index parameters, relations between c_v and each index parameter (i.e. wc , Gs, LL, PL, and PI) are plotted based on the collected data from five locations in Erbil Governate under different depths which are in the range of 4-5m and 8-9m. However, there is no need to analyze the data statically due to the limited data which was provided (Sridharan and Nagaraj, 2004). Hence, Figures 2 to 6 are plotted to distinguish which index parameter is well-correlated with the consolidation coefficient c_v. For each figure, the best fit line is also included in the corresponding figure with a proposed equation of the trend line along with R-squared (R^2) value. From the theoretical analysis trials, it is observed that the Exponential form equation as $[ae^{bx}]$ gives the best fit line in which the c_v is a dependent parameter and the index parameters as an independent. Figure 2 to Figure 6 shows the c_v mostly decreases with increasing of wc, Gs, LL, PL, and PI – which matches with the findings of Sridharan & Nagaraj, 2004; Solanki et. al., (2008); Devi et. al., (2015) and Dehghanian, and Ipek (2022).

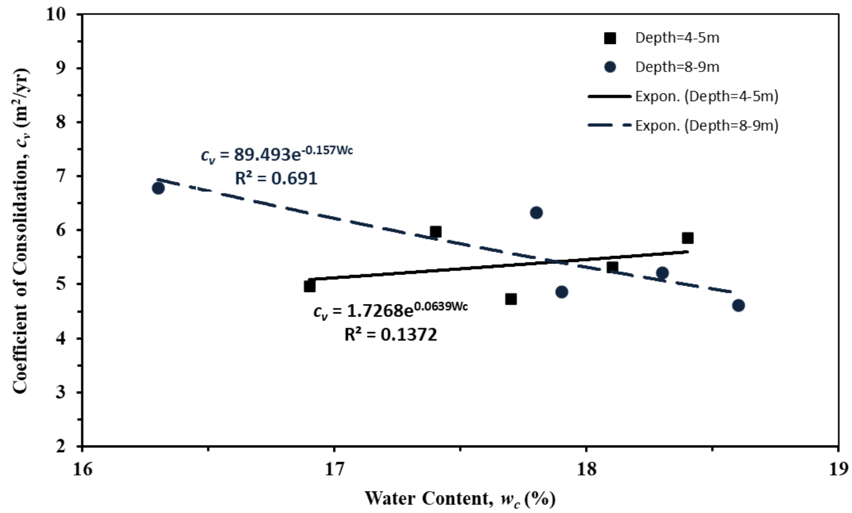

Figure 2: Consolidation coefficient and water content relationship for 4-5 m and 8-9 m soil depths

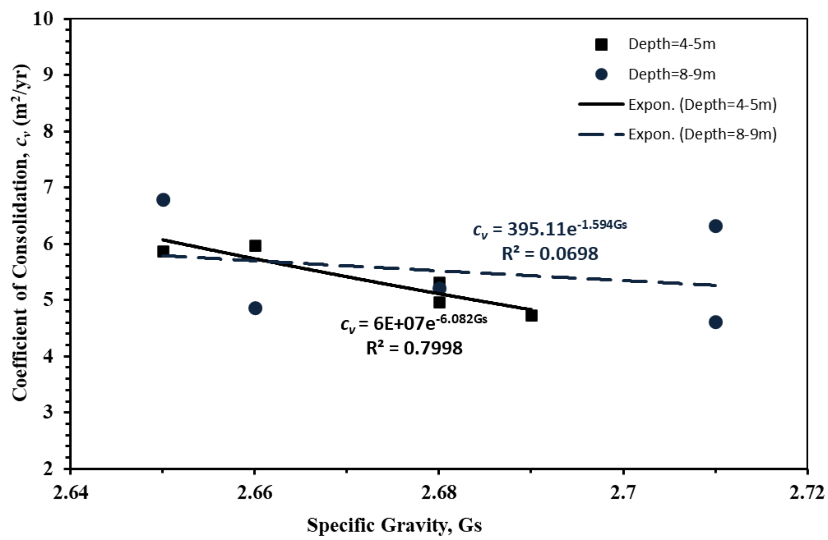

Figure 3: Consolidation coefficient and specific gravity relationship for 4-5 m and 8-9 m soil depths

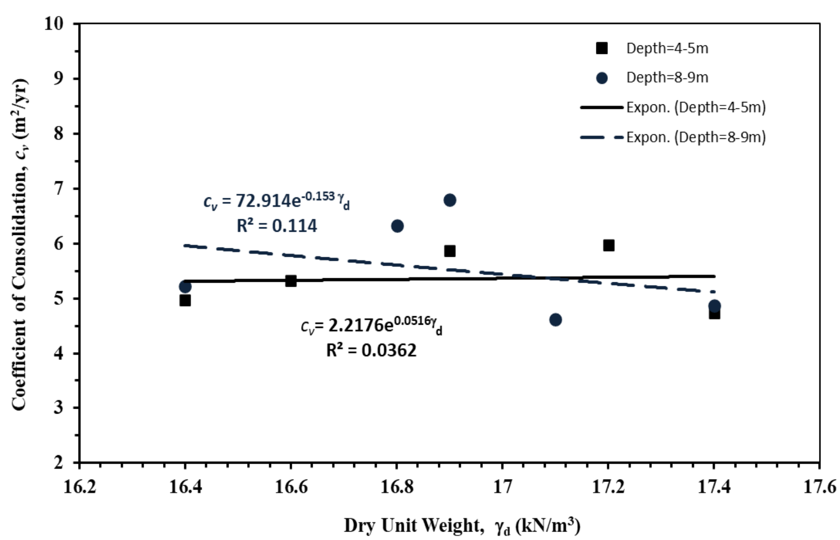

Figure 4: Consolidation coefficient and dry unit weight relationship for 4-5 m and 8-9 m soil depths

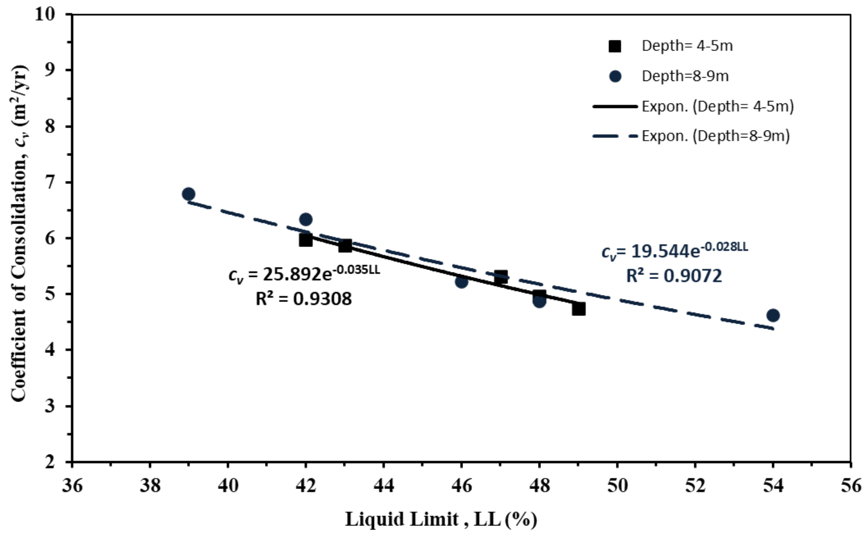

Figure 5: Consolidation coefficient and liquid limit relationship for 4-5 m and 8-9 m soil depths

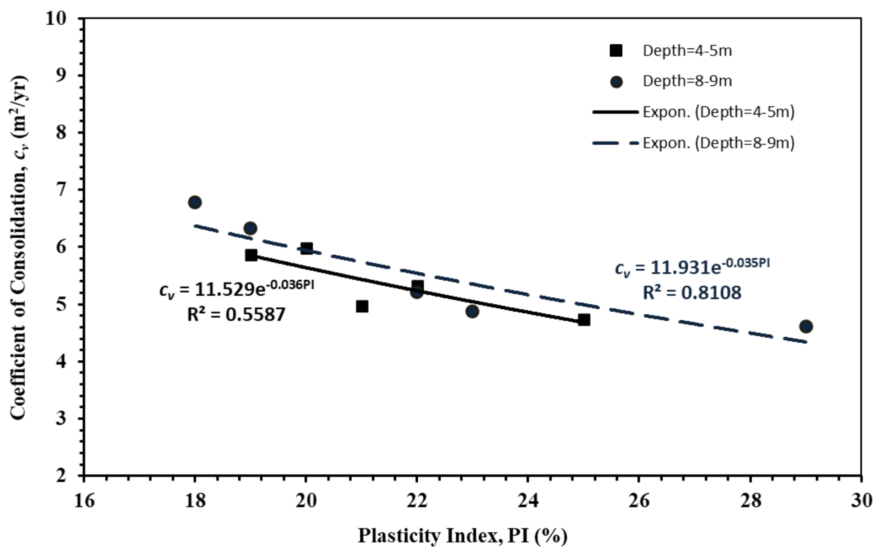

Figure 6: Consolidation coefficient and plasticity index relationship for 4-5 m and 8-9 m soil depths

Referring to the same figures, for comparison, it is found that the liquid limit (i.e., Figure 5) shows the best correlation with the c_v with maximum R2 of 0.9 at the depth of 4-5m and 8-9 m; similar finding was proposed by many researchers (Sridharan & Nagaraj, 2004; Devi et. al., 2015; Soibam et al., 2015; Al-Tae'e and Al-Ameri, 2011). To verify this, recommended liquid limit LL versus coefficient of consolidation c_v relations by Soibam et al. (2015) and AL-Tae'e and AL-Ameri (2011) are presented in Figure 7. From the comparison, it was found the proposed c_v relation has a good agreement with the literature. For the above reason, therefore, Equation 1 and Equation 2 can be proposed for the estimation of the consolidation coefficient c_v based on Liquid Limit LL values for the 4-5m and 8-9m soil depths, respectively.

$$c_v = 25.89\ e^{-0.035\ LL} \quad (1)$$

$$c_v = 19.54\ e^{-0.028\ LL} \quad (2)$$

Where:

c_v is the consolidation coefficient in (m^2/yr), LL stands for the Liquid Limit in (%).

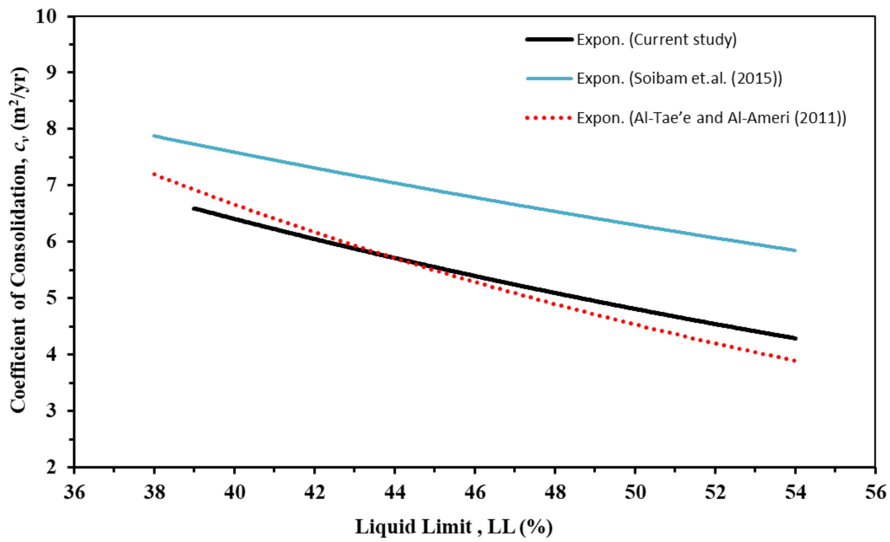

Figure 7: Comparison of the proposed relationship with other researchers

5- CONCLUSIONS

Experimental investigation of Erbil fine soil is analyzed to demonstrate the relation between the consolidation coefficient and soil index parameters. The fine soil classified, as a low plasticity clay and normally consolidated clay, is located at Erbil governate collected from five locations at two different soil depths ranges in 4-5m and 8-9m. The index parameters include water content, dry unit weight, void ratio, and consistency limits. The relations of the consolidation coefficient and the index parameters are compared, and then verified to assess the best correlation between the consolidation coefficient and the index parameters.

From all above relationships, it is concluded that the liquid limit LL has the best correlation with the coefficient of consolidation c_v which can be proposed by a simple equation. Therefore, new equations which are summarized in Table 4 can be applied to estimate the consolidation coefficient based on the liquid limit test for both shallow and deep depths for a normally consolidated clay. This new approach is simple, quick, easy-to-use and economical. It is envisaged that these proposed equations will help engineers in estimating c_v suitable for site investigation, and design foundation in fine-grained soils, based on the liquid limit test only.

Table 4: Proposed consolidation coefficient c_v equations at two different depths

Proposed Equation	Unit	Depth (m)
$c_v = 25.89\, e^{-0.035\, LL}$	m^2/yr	4-5
$c_v = 19.54\, e^{-0.028\, LL}$	m^2/yr	8-9

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