Consolidation Characteristics Assessment of SPT-Derived Clayey Silt Samples Using One-Dimensional Consolidation Test and PLAXIS 2D Analysis

Marc Lin F. Abonales
Department of Civil Engineering, Caraga State University

Joter Genesis R. Palad
Department of Civil Engineering, Caraga State University

Chander Brize E. Daro
Department of Civil Engineering, Caraga State University

Jim Michael M. Racaza
Department of Civil Engineering, Caraga State University

https://doi.org/10.5109/7395701

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 11, pp.1457-1463, 2025-10-30. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

Consolidation Characteristics Assessment of SPT-Derived Clayey Silt Samples Using One-Dimensional Consolidation Test and PLAXIS 2D Analysis

Marc Lin F. Abonales[1,2], Joter Genesis R. Palad[1], Chander Brize E. Daro[1], Jim Michael M. Racaza[1]
[1]Department of Civil Engineering, Caraga State University
[2]Caraga Center for Geo-Informatics (CCGeo), Caraga State University
Corresponding author email: mlfabonales@carsu.edu.ph, jotergenesis.palad@carsu.edu.ph, chanderbrize.daro@carsu.edu.ph, jimmichael.racaza@carsu.edu.ph

Abstract: *Understanding consolidation characteristics is essential for safe infrastructure design. However, sample disturbance, particularly from Standard Penetration Tests (SPT), can lead to inaccurate soil parameters. This study addresses this research gap by comparing the consolidation behavior of disturbed clayey silt samples from SPT with results from PLAXIS 2D simulations, which use undisturbed soil parameters derived from empirical correlations. Methodology included field sampling, one-dimensional consolidation testing, and finite element analysis in PLAXIS 2D. Key findings showed that disturbed samples yielded lower preconsolidation pressure, compression index, and coefficient of consolidation. In contrast, PLAXIS 2D results aligned with values expected for undisturbed soils. The implications suggest that numerical modeling, even with SPT data, provides a practical and more reliable alternative for estimating soil consolidation characteristics, especially when undisturbed samples are unavailable. This approach enhances geotechnical analysis, promoting safer and more efficient foundation design.*

Keywords: Consolidation; PLAXIS 2D; Disturbed Sample; Clayey Silt

1. INTRODUCTION

Karl Terzaghi, the father of soil mechanics, developed a theory in which he stated that if load is applied on a saturated layer like clay, the pore water pressure increases, and over time, as water drains from the soil's voids, the soil structure compresses [1], such is the theory of consolidation. In the context of engineering and construction, when a building is constructed, the soil beneath the building reacts to the loading of the building, which causes the underlying soil to consolidate or compress due to the expulsion of moisture from the soil's voids. Therefore, understanding the soil's consolidation characteristics is vital to ensure the stability and safety of any infrastructure. Fine-grained soils, particularly clays and silts, are recognized for their high compressibility and, when exhibiting high plasticity, are also prone to significant volume changes, making them inherently expansive in nature [22].

The consolidation characteristics of soil, including key parameters such as the coefficient of consolidation, compression index, and preconsolidation pressure, are critical for safe and effective foundation design and infrastructure development. However, these parameters are sensitive to sample disturbance [2], which can significantly affect the accuracy of consolidation test results and the interpretation of the consolidation behavior of soil, potentially leading to unsafe or uneconomical designs. The problem arises as the most common method of acquiring subsurface soil samples is drilling by boring methods, which has a significant effect on the disturbance of the samples [3].

PLAXIS 2D, a geotechnical engineering software created by Bentley, can be used to conduct two-dimensional (2D) finite element analysis for studies and analyses involving soil and rocks, including soil consolidation, without the use of the actual sample. This is very useful as it allows the treatment of disturbed samples using published correlation formulas, which can be very helpful in cases where only disturbed samples are present. Furthermore, PLAXIS 2D has proven its reliability in numerous studies, such as the study of Hakim and Prianto [4], wherein results showed similar consolidation settlement using empirical analysis and finite element analysis with PLAXIS 2D. Standard Penetration Test (SPT) and Cone Penetration Test (CPT) were conducted at 60 meters in depth, and empirical analysis produced a settlement of 0.144 meters in 47.7 days for a 90% degree of consolidation, whilst PLAXIS 2D calculations produced a settlement of 0.147 meters in 47 days.

In anticipation of future infrastructure expansion, proactive research aimed at improving the safety and efficiency of construction practices is imperative. One critical aspect is thorough soil investigation, particularly in understanding consolidation behavior, which directly influences foundation performance. This study aims to advance such efforts by examining how sample disturbance resulting from Standard Penetration Test (SPT) procedures impacts the consolidation characteristics of clayey silt soils. By comparing laboratory results with simulations generated through PLAXIS 2D, the study provides valuable insights into the reliability of disturbed samples and the potential of numerical modeling as a more accurate and practical alternative for geotechnical evaluation.

2. METHODOLOGY

The general methodology employed in the study provides a systematic approach to obtaining soil data and the consolidation characteristics of the soil. The process includes wash boring sampling, standard penetration tests (SPT), one-dimensional consolidation (oedometer) tests, and PLAXIS 2D simulations. This study aims to identify the significance of sample disturbance in determining the consolidation characteristics of disturbed samples.

2.1 Study Area
The study was conducted in Caraga State University (CSU), Ampayon, Butuan City, Agusan del Norte, Philippines. In CSU, 32 hectares are designated for academic buildings and support facilities, while the remaining 200 hectares are designated for the university's production, research, and extension projects [5]. Multiple soil investigations conducted by a soil testing service inside the 32-hectare land designated for academic infrastructures and facilities in Caraga State University showed uniform soil characteristics. From the surface to 4 meters down, the soil consisted of clayey silt, or a mixture of clayey silt and sandy silt. Below the groundwater table, from 4 to 15 meters, the soil was exclusively medium-stiff silty clay with high plasticity.

2.2 Sample Collection
2.2.1 Wash Boring
Two boreholes were drilled on the site located north of the HERO Learnings Common. The boreholes were advanced using wash boring methods. Soil samples were collected at every 1.5m depth of the soil layer. However, only the sample at 4.5 m depth was used in the laboratory testing for consolidation testing.

2.2.2 Standard Penetration Test
A donut-hammer manual type with a free fall of 0.7m was used to determine SPT N-values. These N-values can then be used to correlate soil properties such as soil modulus and internal friction of similar soils [6]. Standard penetration tests were conducted every 1.5m throughout the 5m depth.

2.3 Determination of Soil Properties
The soil samples collected at a depth of 4.5 meters underwent separate laboratory testing from the one-dimensional consolidation test to aid in determining the consolidation parameters. The soil classification, Atterberg limits, moisture content, and specific gravity were identified.

2.4 One-Dimensional Consolidation Test
The consolidation test adopted the first method of the ASTM D2435/D2435 M-11, or the "Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading," which involved applying load increments with a constant duration of twenty-four (24) hours [7]. The test was conducted for eight (8) consecutive days, with load increments doubling at each day. Table 1 presents the load increments after every 24 hours. Each day, dial reading was taken at every 6s, 15s, 30s, 1m, 2m, 4m, 8m, 15m, 30m, 1h, 2h, 4h, 8h, and 24h.

2.5 PLAXIS 2D Simulation
2.5.1 Soil Parameters
Input values for material definitions only include limiting values for the hardening soil model and are mostly derived from SPT-N correlated values of similar soil properties. Parameters that are not specified are automatically calculated by PLAXIS 2D based on the limiting values. Table 2 shows the material parameters needed for the model and the equations used to determine the parameters.

Table 1. Load Increments

Day	Weights (kg)			Soil Sample Bearing Pressure (kPa)
	Weight (kg)	Quantity (pcs)	Total Weight (kg)	
1	0.319	1	0.319	12.5
2	0.319	1	0.638	25
3	0.637	1	1.275	50
4	1.275	1	2.55	100
5	2.55	1	5.1	200
6	2.55	2	10.2	400
7	5.1	2	20.4	800
8	5.4	4	40.8	1600

Table 2. Material Parameters and Equations to be used for PLAXIS 2D Input

Property	Equation
Unit Weight (γ)	$\gamma = 42.42w^{-0.239}$ [11]
Saturated Unit Weight (γ_{sat})	$\gamma_{sat} = \frac{(G_S+e)\gamma_w}{1+e}$ [9]
Void Ratio (e)	$e = \frac{n}{(1-n)}$ [9]
Reference Stiffness Modulus (E_{50}^{ref})	$E_{50} = E_{50}^{ref}(\frac{c cos\phi - \sigma_3 sin\phi}{c cos\phi - p^{ref} sin\phi})^m$ [12]
Undrained Cohesion (c')	$C_u = \frac{1}{2}q_u$ [1]
Angle of Internal Friction (ϕ)	$\phi = 27.1 + 0.3 \times N_{60} - 0.00054 \times N_{60}^2$ [13]
Permeability (k)	$k = 10^{(-4.52-1.37I_c)}$ [14]

2.5.2 Soil Model
An axisymmetric model was selected as it is used for circular structures with a uniform radial cross section and loading scheme around the central axis [17]. In order to produce more accurate results, a 15-noded triangle element setting was used. In the structures tab, the soil model was created using the polygon tool with dimensions of 0.02 m and 0.0309 m. To provide even more accurate results, the global mesh was set to "very fine", which means that the 15-noded triangles are much finer relative to the size of the model, increasing the calculation time while improving accuracy [17]. The water level was then set above the soil model, and boundary conditions were set to "closed" on the sides and "seepage" on the top and bottom portions of the model. Lastly, a line load was placed at the top of the model. A hardening soil model was used for the material model. The hardening soil model is an advanced model for simulating the behavior of different types of soil, both soft soils and stiff soils [15]. Theoretically, a much rounder curve will be generated from dial readings since hardening soil models shows decreasing stiffness when subjected to primary deviatoric loading [16].

2.6 Staged Construction
The loading criteria of the laboratory one-dimensional consolidation test shall be adapted. The default setting was set for the initial phase. For the loading steps, the

calculation type was set to consolidation, with time intervals set to match the dial reading time in the actual one-dimensional consolidation test in minutes. This means that each dial reading had separate steps connected at the previous loading stage. For every load increment, a new step is added with a time interval set to 1440 m, and the dial reading steps are moved to the new load increment. Project files are saved for every load increment.

2.7 Determination of Consolidation Parameters

Two widely used methods of determining the consolidation coefficient (c_v) were employed, namely, Casagrande's logarithm of time method [7] and Taylor's square root of time fitting method [8], while the compression index and pre-consolidation pressure were determined using an *e*–log *p* curve.

2.7.1 Casagrande's Logarithm of Time

In Casagrande's method [7], the intersection point of the line tangent to the straight-line portion of the primary compression curve and the line tangent to the secondary compression curve were identified to estimate the time required to achieve 100% primary compression (t_{100}) and the corresponding deformation (d_{100}) of the sample. Two points were then selected on the upper curved portion of the consolidation graph: one at time t_1 and the other at time t_2, where $t_2 = 4t_1$, including their corresponding deformations at d_1 and d_2, respectively. The difference (Δd) of d_1 and Δd was then calculated, and the deformation at 0% primary consolidation (d_0) was determined by subtracting d_1 and Δd. Following, the average of d_0 and d_{100}, which is the deformation at 50% primary consolidation (d_{50}), is then calculated, and the corresponding time at 50% primary consolidation (t_{50}) is identified. Furthermore, the height of drainage path (H_{dr}) was calculated by subtracting the deformation at 50% primary consolidation (d_{50}) to the initial height of the sample, then divided by 2 as shown in Eq. 1. Lastly, the coefficient of consolidation (c_v) from Casagrande's Logarithm of Time Fitting Method was calculated by using the formula shown in Eq. 2.

$$H_{dr} = \frac{H_0 - d_{50}}{2}. \quad (1)$$

$$c_v = 0.197\left(\frac{H_{dr}^2}{t_{50}}\right). \quad (2)$$

2.7.2 Taylor's Square Root of Time

In Taylor's Square Root of Time Fitting Method [8], a tangent was drawn to the linear segment of the curve at a chosen deformation, denoted as Δ, then a straight line was extended from the origin (d_0), with an abscissa of 1.15Δ. The intersection of this line with the experimental curve indicated the time (t_{90}) and corresponding deformation (d_{90}) for achieving 90% primary consolidation. The deformation at 100% primary consolidation was then calculated, as shown in Eq. 3

$$d_{100} = d_0 + 1.11(d_{90} - d_0). \quad (3)$$

The deformation at 50% primary consolidation (d_{50}) and the height of drainage path (H_{dr}) were then calculated, and the coefficient of consolidation was calculated using the following formula:

$$c_v = 0.848\left(\frac{H_{dr}^2}{t_{90}}\right) \quad (4)$$

2.7.3 Void Ratio – Log of Pressure (*e* – log *p*) Plot

The final height at each load increment was used in the *e*–log *p* plot [9], together with the obtained moisture content and specific gravity of the soil samples. Firstly, the initial void ratio (e_0) was identified using the formula shown in Eq. 5.

$$e_0 = \frac{V_0 - \frac{M_d}{G_s p_w}}{\frac{M_d}{G_s p_w}}. \quad (5)$$

Where:

V_0 = initial volume of sample
M_d = dry mass
G_s = specific gravity
p_w = density of water

The height of solids (H_0) was then calculated by using the calculated initial void ratio (e_0) and the initial height (H_0) of the specimen, as shown in Eq. 6.

$$H_s = \frac{H_0}{1 + e_0}. \quad (6)$$

Following, the final height (H) at every load increment was subtracted by the height of solids (H_s) to obtain the height of voids (H_v). Lastly, the final step before plotting the graph is to determine the void ratio (e) at each load increment, which is calculated by dividing the height of voids (H_v) by the height of solids (H_s).

In the *e*–log *p* curve, the point that has the smallest radius of curvature is determined. A straight line connecting from the upper curved portion and the virgin compression curve (lower linear portion) is then drawn. Next, a bisector line is drawn between these two straight lines, and the intersection of this line and the line that connects to the lower linear portion is the maximum pre-consolidation pressure [10]. To calculate the compression index, two points are selected along the lower linear portion of the curve or also known as the virgin compression curve. The two points possess void ratios e_1 and e_2, and stresses p_1 and p_2, respectively, and are selected so that $e_1 > e_2$ and $p_2 > p_1$. Compression index [9][21] is then expressed as:

$$C_c = \left(\frac{e_1 - e_2}{\log \frac{p_2}{p_1}}\right). \quad (7)$$

3 RESULTS AND DISCUSSION

This chapter presents the study's core findings, offering a detailed discussion and interpretation of the results obtained through one-dimensional consolidation tests and PLAXIS 2D analysis using SPT-derived clayey silt samples.

3.1 Soil Parameters

A geotechnical investigation, involving two boreholes using the Standard Penetration Test (SPT) with wash boring techniques, was conducted on a lot north of the HERO Learning Commons at Caraga State University, Main Campus. Figures 1 and 2 show the bore logs for BH-01 and BH-02, which include the material description at each depth, and their SPT N values and corrected N values.

Depth	Drilling Method	Material Description	Blows per 15 cm			SPT N Value	Corrected SPT N Value (N60)
0.00 - 1.00	Wash Boring	Brown, Clayey Silt of Medium Plasticity	3	3	4	7	5
1.05 - 1.50	SPT						
GROUNDWATER LEVEL							
1.50 - 2.50	Wash Boring	Brown, Clayey Silt of Medium Plasticity	2	2	2	4	3
2.55 - 3.00	SPT						
3.00 - 4.00	Wash Boring	Gray, Clayey Silt of Medium Plasticity	2	2	2	4	3
4.05 - 4.50	SPT						

Fig. 1. BH-01 Bore Log

Depth	Drilling Method	Material Description	Blows per 15 cm			SPT N Value	Corrected SPT N Value (N60)
0.00 - 1.00	Wash Boring	Brown, Clayey Silt of Medium Plasticity	6	6	5	11	8
1.05 - 1.50	SPT						
GROUNDWATER LEVEL							
1.50 - 2.50	Wash Boring	Brown, Clayey Silt of Medium Plasticity	2	1	1	2	2
2.55 - 3.00	SPT						
3.00 - 4.00	Wash Boring	Gray, Clayey Silt of Medium Plasticity	1	1	1	2	2
4.05 - 4.50	SPT						

Fig. 2. BH-02 Bore Log

Soil samples were collected at a depth of 4.05 to 4.50 meters below the natural ground level, which were used for multiple laboratory tests to determine the soil parameters of the investigated site, namely the particle size distribution, soil classification, Atterberg limits, moisture content, and specific gravity. Table 3 shows the summary of the laboratory testing and soil parameters for the two (2) boreholes.

Table 3. Soil Sample Parameters

	Borehole No.	
	01	**02**
Sample Depth (m)	4.05 to 4.50	4.05 to 4.50
Liquid Limit (%)	58.3	52.1
Plastic Limit (%)	31.5	29.9
Plasticity Index (%)	26.8	22.2
Natural Moisture Content (%)	38.25	35.88
Specific Gravity	2.68	2.68
USCS Soil Classification	MH (Clayey Silt)	MH (Clayey Silt)

3.2 One-Dimensional Consolidation Test

A one-dimensional consolidation test as per ASTM D2435/D2435 M-11 was conducted for each sample collected from the two (2) boreholes. The soil samples were collected using Standard Penetration Tests (SPTs) with wash boring techniques; therefore, the samples were disturbed as shown in Figure 3. The soil samples were remolded to fit inside the consolidation ring, with an area of 30 cm^2 and a height of 2 cm.

Fig. 3. BH-01 and BH-02 Soil Samples

The one-dimensional consolidation test was conducted for a total of eight (8) days, with each day designated to a load increment. During the first half of the consolidation test, the sample from BH-02 was settling more slowly than the sample from BH-01, with a gap of 0.31 mm of settlement by day 5. At the end of the test, the soil sample from BH-02 settled 4.365 millimeters, whilst the soil sample from BH-01 settled 4.47 millimeters, closing the settlement by 0.105 mm. Figure 4 shows the settlement of the soil samples at each load increment from the one-dimensional consolidation test.

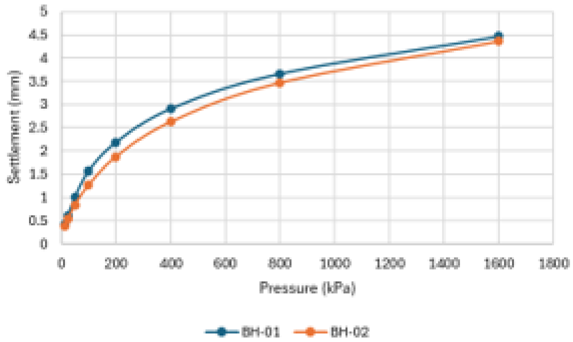

Fig. 4. Settlement at each Load Increment (mm) from the One-Dimensional Consolidation Test

3.3 PLAXIS 2D Analysis

A one-dimensional consolidation test was replicated virtually with finite element method (FEM) using the Hardening Soil Model in PLAXIS 2D version 2024.2 by Bentley Systems. The parameters used in the analysis were derived from SPT N-values correlations. Therefore, the sample is treated as an undisturbed sample, and the soil conditions are not the same as those of the disturbed sample used in the actual one-dimensional consolidation test. Table 4 shows the parameter values for the PLAXIS 2D input. Additionally, for uniformity, the same sample thickness, loading sequence, and loading duration as the laboratory consolidation test were employed. The dial reading was also noted at the same time increments as the laboratory test.

Same with the one-dimensional consolidation test, eight (8) loading increments were also applied to a 20-mm-thick soil sample for 24 hours each. The analysis using PLAXIS 2D showed that the settlement was slower during the lighter loading stages and quicker during the heavier loading stages, particularly in the 800 kPa and 1600 kPa loading stages. The sample for BH-01 settled a total of 6.406 mm for the whole analysis, whilst the sample for BH-02 settled to a total of 7.235 mm. Figure 5 shows the settlement of the soil samples at each load increment using the PLAXIS 2D.

Table 4. Material Parameter Values for PLAXIS 2D Input

Property	Borehole No. 01	Borehole No. 02
Unit Weight, γ (kN/m^3)	17.76	18.03
Saturated Unit Weight, γ_{sat} (kN/m^3)	19.67	19.68
Void Ratio, e	0.667	0.667
Reference Stiffness Modulus, E_{50}^{ref} (kPa)	2484	2202
Undrained Cohesion, c' (kPa)	25	25
Angle of Internal Friction, ϕ (°)	27.95	27.7
Permeability, k (m/s)	4.38e^{-8}	4.38e^{-8}

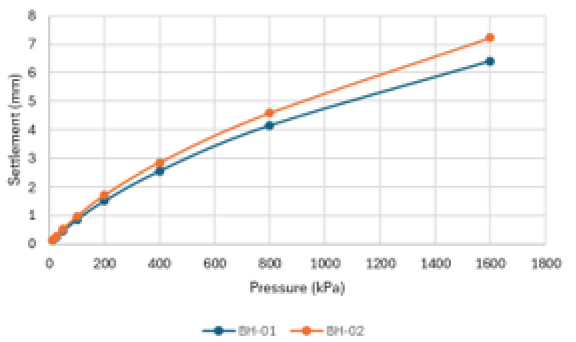

Fig. 5. Settlement at each Load Increment (mm) from PLAXIS 2D

3.4 Assessment of Results from One-Dimensional Consolidation Test and PLAXIS 2D Analysis

The results from the one-dimensional consolidation test and the PLAXIS 2D analysis were compared and analyzed. This assessment also involved describing any observable patterns from both methods and comparing these findings with those reported in related published studies.

3.4.1 Void Ratio versus Log of Pressure Plot

The void ratio–log of pressure plot for the one-dimensional consolidation test appeared more linear, particularly with the BH-01 sample, in comparison to the void ratio–log of pressure plot for the PLAXIS 2D analysis, where more curvature and slope are present in the graph, as shown in Figures 6 and 7. This behavior is consistent with a study by Dumanlilar et al. [2], wherein they determined that as disturbance rate increases, the slope of the curve of the void ratio–log of pressure plot gradually decreases, or the slope appears flatter, which is what happened in this case. The one-dimensional consolidation test used a disturbed sample obtained from SPT sampling with wash boring techniques, whilst with PLAXIS 2D analysis, the soil sample was treated as undisturbed using published correlations from SPT N-values, hence the different curvature of the void ratio–log of pressure plot for the two methods.

3.4.2 Coefficient of Consolidation

When comparing the results from the PLAXIS 2D analysis with the laboratory test results, it can clearly be seen from Figures 8 and 11 that the c_v values from the PLAXIS 2D analysis are generally smaller than the c_v values from the one-dimensional consolidation test. Shogaki and Kaneko [19] investigated the effects of sample disturbance on the consolidation parameters of soft clay, wherein they determined that when soils are disturbed, the c_v values are smaller. However, in this case, the coefficient of consolidation is smaller with the PLAXIS 2D, which represents the soil in an undisturbed state. Additionally, from the four figures shown, it can be observed that there aren't many similarities in the c_v values before the 800 kPa loading stage; beyond this mark, the two methods decreased in c_v values.

3.4.3 Preconsolidation Pressure and Compression Index

The preconsolidation pressure and the compression index obtained from the PLAXIS 2D analysis were both larger than those obtained from the one-dimensional consolidation test. As shown in Table 5, the preconsolidation pressure for BH-01 increased from 94.166 kPa to 338.504 kPa, whilst for the BH-02 sample, the preconsolidation pressure increased from 129.875 kPa to 345.025 kPa. This increase in preconsolidation pressure from a disturbed state to an undisturbed state is consistent with the study of Lunne et al. [20], wherein they stated that empirical procedures like Casagrande's void ratio–log of pressure plot gave smaller preconsolidation pressures for severely disturbed specimens. Furthermore, the compression index for both samples also increased from 0.398 to 0.440 for BH-01 and from 0.469 to 0.481 for BH-02, which follows the trend of the study by Dumanlilar [2], who stated that the compression index decreases with sample disturbance.

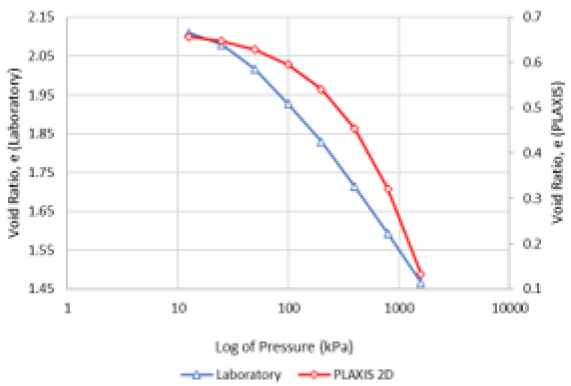

Fig. 6. Void Ratio versus Log of Pressure Plot for BH-01

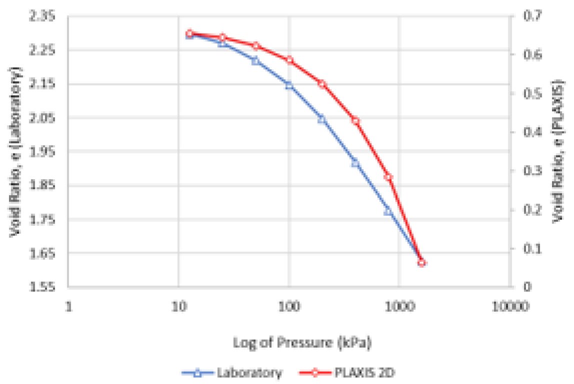

Fig. 7. Void Ratio versus Log of Pressure Plot for BH-02

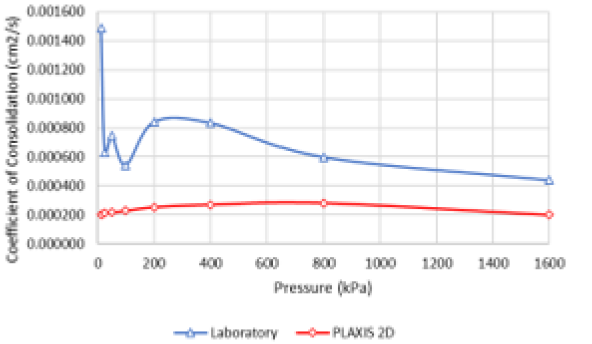

Fig. 8. Coefficient of Consolidation versus Pressure Plot using Casagrande's Method for BH-01

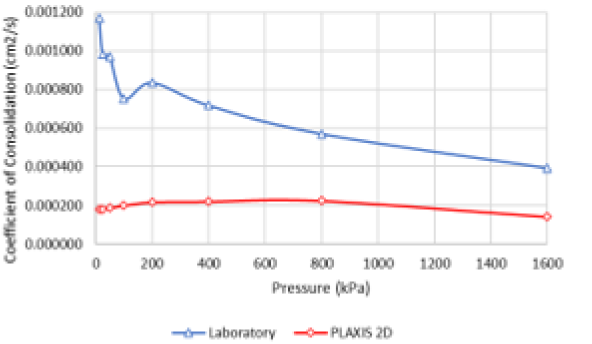

Fig. 9. Coefficient of Consolidation versus Pressure Plot using Casagrande's Method for BH-02

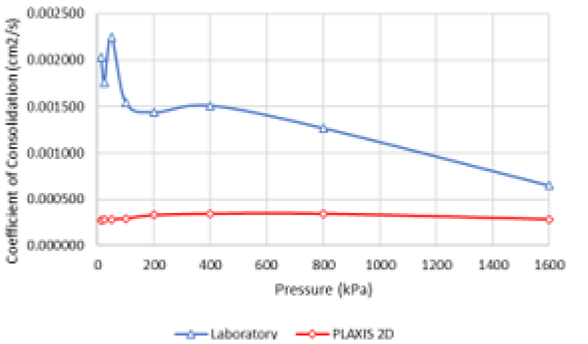

Fig. 10. Coefficient of Consolidation versus Pressure Plot using Taylor's Method for BH-01

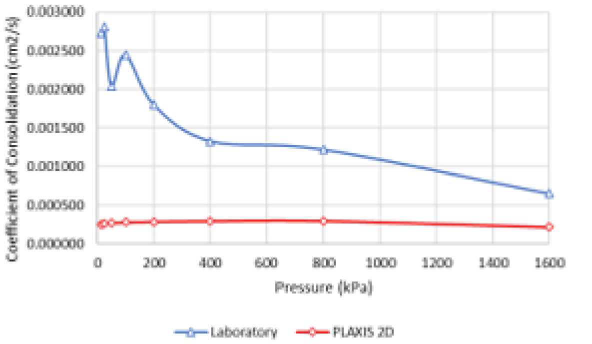

Fig. 11. Coefficient of Consolidation versus Pressure Plot using Taylor's Method for BH-02

Table 5. Summary of p_c and C_c Values.

Soil Parameter	BH-01		BH-02	
	Lab Test	PLAXIS 2D	Lab Test	PLAXIS 2D
p_c (kPa)	94.166	338.504	129.875	345.025
C_c	0.398	0.440	0.469	0.481

4 CONCLUSION AND RECOMMENDATIONS

This chapter summarizes the study's key findings and suggests specific actions or plans to overcome the identified challenges and limitations in the consolidation characteristics assessment of SPT-derived clayey silt samples using one-dimensional consolidation test and finite element analysis in PLAXIS 2D.

4.1 Conclusion

This study systematically assessed the consolidation characteristics of SPT-derived clayey silt samples using both laboratory one-dimensional consolidation testing and PLAXIS 2D finite element modeling. The findings underscore the significant impact of sample disturbance on the accuracy of soil consolidation parameters, including the coefficient of consolidation (c_v), preconsolidation pressure (p_c), and compression index (C_c). Laboratory results from disturbed samples exhibited more linear void ratio–log pressure curves and lower consolidation parameters, reflecting compromised soil stiffness and strength. In contrast, PLAXIS 2D simulations, based on SPT N-value correlations and undisturbed assumptions, produced higher settlement, steeper consolidation curves, and greater p_c and C_c values. These observations align with existing literature on the detrimental effects of sample disturbance.

The results confirm that numerical modeling, when calibrated with empirical correlations, offers a more consistent and potentially accurate alternative for assessing soil consolidation behavior, especially in scenarios where undisturbed samples are unavailable. This approach is particularly beneficial for preliminary geotechnical evaluations and infrastructure planning in areas with soft or sensitive soils. Therefore, integrating numerical simulations into standard practice enhances both the safety and efficiency of geotechnical design processes. Continued refinement of models and validation through undisturbed samples remains essential to further improve the reliability of such analyses.

4.2 Recommendations

The following recommendations are proposed to further improve the determination and assessment of disturbed samples obtained from SPT sampling with wash boring techniques:

1. Triaxial Tests
   In PLAXIS 2D, parameters such as soil modulus, cohesion, and friction angle can be determined from a triaxial test. These parameters are needed in order to complete a soil model. To simulate the consolidation of a soil sample as accurately as possible, triaxial tests are suggested to get the exact values instead of correlations.
2. More Soil Models
   Many types of soil models can be used to simulate soil consolidation properties. Soft soil model, for example, is a good soil model to use for high compressibility, but it needs the compaction and swelling indices, which can be determined through one-dimensional consolidation tests.
3. Use of Undisturbed Samples
   The use of undisturbed samples, such as those obtained from Shelby tubes or block samples from test pits, is highly beneficial in assessing and determining consolidation parameters. These

samples provide more accurate and reliable results and serve as a benchmark for comparing disturbed samples in both one-dimensional consolidation tests and PLAXIS 2D analysis. Additionally, they help evaluate the extent of sampling disturbance in determining consolidation parameters and assess the accuracy of the PLAXIS 2D analysis.

4. Use of More Samples
   Despite showing uniform soil characteristics, the use of more samples could still be beneficial in the assessment of consolidation parameters. As shown from the results of the two samples utilized in the study, there were still some differences in the settlement and consolidation parameters. Therefore, more samples could yield a more reliable assessment.
5. Continued Research
   Further research should be conducted to explore the integration of finite element analysis in geotechnical investigations, particularly with the consolidation characteristics of soils. This includes refining numerical models to better capture soil behavior under varying stress conditions, and expanding the use of in-situ testing methods and correlating their results with both laboratory and numerical analyses, which can enhance the accuracy and reliability of consolidation parameter estimation.

5 REFERENCES

[1] Terzaghi, K., Peck, R., Mesri, G. (1996), Soil Mechanics in Engineering Practice 3rd Edition, JOHN WILEY & SONS, INC.

[2] Dumanlilar, M., Fener, M., & Balci, M. C. (2022). Investigation of the Sample Disturbance Effects on Consolidation Parameters Obtained from Conventional Oedometer Tests. Mühendislik Bilimlire Ve Araştirmalari Dergisi, 4(2), 278–286.

[3] Suyama, K., & Oya, S. (1962). Significance of boring in sampling. Soils and Foundations, 2(2), 35-50.

[4] Hakim, A., & Prianto, K. (2018). Analysis of Consolidation Settlement: A Case Study on State Islamic University of Sunan Ampel Campus. Proceedings of the Built 101 Environment, Science and Technology International Conference (BEST ICON 2018), 172–176.

[5] Caraga State University. (n.d.). Campus Map and Virtual Tour. https://www.carsu.edu.ph/?q=page/campus-map-and-virtual-tour

[6] Verbrugge, J.-C., & Schroeder, C. (2018). Geotechnical Correlations for Soils and Rocks. ISTE Ltd.

[7] Casagrande, A., & Fadum, R. E. (1940). Notes on soil testing for engineering purposes.

[8] Taylor, D. W. (1948). Fundamentals of soil mechanics (Vol. 66, No. 2, p. 161). LWW.

[9] Das, B. M., & Sobhan, K. (1990). Principles of geotechnical engineering.

[10] Das, B. M. (2019). Advanced soil mechanics. CRC press.

[11] Vidalie, J. F. (1977). Relations entre les propriétés physico-chimiques et les caractéristiques mécaniques des sols compressibles (LPC Report No. 65). Laboratoire Central des Ponts et Chaussées.

[12] PLAXIS. (n.d.). PLAXIS Version 8 Material Models Manual

[13] Peck, R. B., Hanson, W. E., & Thornburn, T. H. (1991). *Foundation engineering*. John Wiley & Sons.

[14] Robertson P.K., Cabal K.L., Guide to Cone Penetration Testing for Geotechnical Engineering, Gregg Drilling & Testing, Inc., 6th ed., 2015.

[15] Schanz, T., Vermeer, P.A., Bonnier, P.G. (1999). The hardening-soil model: Formulation and verification. In R.B.J. Brinkgreve, Beyond 2000 in Computational Geotechnics, Balkema, Rotterdam. 281–290

[16] Kondner, R.L. (1963). A hyperbolic stress strain formulation for sands. 2. Pan. Am. ICOSFE Brazil, 1, 289–324.

[17] Bentley Systems. (2025). PLAXIS 2D 2024.3 Reference Manual.

[18] Shukla, S., Sivakugan, N., & Das, B. (2009). Methods for determination of the coefficient of consolidation and field observations of time rate of settlement — an overview. International Journal of Geotechnical Engineering, 3(1), 89–108. https://doi.org/10.3328/ijge.2009.03.01.89-108

[19] Shogaki, T., & Kaneko, M. (1994). Effects of sample disturbance on strength and consolidation parameters of soft clay. SOILS AND FOUNDATIONS, 34(3), 1–10. https://doi.org/10.3208/sandf1972.34.3_1

[20] Lunne, T., Berre, T., Andersen, K. H., Sjursen, M., & Mortensen, N. (2008). Effects of sample disturbance on consolidation behaviour of soft marine Norwegian clays. https://doi.org/10.1139/t06-040

[21] Co, S. C. & et. al. (2024). Estimation of compression index using genetic algorithm approach. Proceedings of the 10th International Exchange and Innovation Conference on Engineering & Sciences (IEICES) (Vol. 10, pp. 379–384). https://doi.org/10.5109/7323289

[22] Adajar, M. A. & et. al. (2024). Utilization of agricultural wastes in enhancing strength and reducing shrink-swell potential of expansive soils. Proceedings of the 10th International Exchange and Innovation Conference on Engineering & Sciences (IEICES) (Vol. 10, pp. 121–127). https://doi.org/10.5109/7323252