A Geotechnical Analysis of Clayey Soil Settlement in Baghdad: An Experimental Study

Amenah Adnan Shakir Al-Mohammedi
Department of Civil Engineering, College of Engineering, University of Al Maarif, Iraq
Amenah@uoa.edu.iq (corresponding author)

Received: 3 June 2025 | Revised: 23 June 2025 | Accepted: 4 July 2025

 DOI: https://doi.org/10.48084/etasr.12529

ABSTRACT

This experimental study analyzed the settlement behavior of clayey soils in Baghdad through standardized geotechnical laboratory tests. Ten representative soil samples were collected from multiple urban zones and tested for water content, Atterberg limits, dry density, permeability, and consolidation. The spatial distribution of the sampling sites was documented to reflect the typical clay-rich conditions within the city. The relationships between the physical parameters and settlement were evaluated statistically, and predictive models were developed to estimate the settlement potential. The results highlighted that the moisture content and dry density are the most influential factors affecting soil the compressibility.

Keywords-soil; geotechnical properties; soil settlement; Baghdad

I. INTRODUCTION

Clayey soil settlement presents a major geotechnical challenge in urban areas with expansive clay and variable groundwater levels, such as Baghdad. The city suffers from chronic foundation distress owing to compressible clay layers, which leads to uneven settlement, cracks in structures, and damage to the underground infrastructure [1, 2]. While previous studies have explored the soil behavior in Iraq, many have relied on localized case-specific data or empirical estimation methods without spatially distributed laboratory validation. This study addresses this gap by conducting a laboratory-based experimental analysis of representative clayey soils from Baghdad and investigating how key physical and mechanical parameters influence the settlement behavior [3, 4].

The soil profile of Baghdad and its associated geotechnical features have been analyzed. The area is mostly made up of alluvial clayey deposits with low permeability and high plasticity [5, 6]. The existing methods for predicting subsidence tend to be based on empirical correlations for a specific site and on testing, including oedometer and consolidation tests. These methods fail to consider the wide-ranging spatial and temporal changes present in the subsurface conditions [7, 8]. The natural water content, Atterberg limits, dry density, permeability, and plasticity are the primary factors determining the settlement potential of the soil [9, 10].

The compressibility of fine-grained soils, particularly clays, is significantly affected by their mineralogy, initial water content, and stress history [11, 12]. Studies in both global and regional contexts have shown that the high plasticity and natural moisture content contribute greatly to the settlement behavior, especially under variable climatic and loading conditions [13, 14]. It has been emphasized that such soils require careful laboratory evaluation, including classification and consolidation testing, to assess the potential deformation accurately [15-17].

In regions such as Baghdad, these parameters are especially relevant because the seasonal moisture fluctuations and construction loads can significantly impact the soil deformation [18, 19]. Investigations have confirmed the importance of considering the local clay behavior under saturated conditions, similar to those observed in the Iraqi environment [20]. Moreover, the swelling and shrinkage potential of expansive soils have been well documented [21], and the pore-pressure theory provides a solid framework for understanding the settlement under saturated loading conditions.

The present study provides an applied geotechnical analysis of the subsidence of clayey soils in Baghdad using basic laboratory tests [22]. The objective is to determine the interdependence among significant properties of the soil and the resulting behavior of the settlement. The current study is based on data from representative soil samples obtained from the Baghdad region and carries out a statistical evaluation of relevant parameters, such as water content, liquid and plastic limits, permeability, and dry density. This effort intends to advance the engineering practice in Iraq by contributing practical information and site-specific data through a classical geotechnical approach that promotes safe and economical design. This work expands upon previous experimental studies, which explored the influence of the temperature, additives, and treatment conditions on the behavior of soils in Iraq [23-26].

II. METHODOLOGY

A. *Soil Sampling and Study Area*

In this research, clayey soil samples, representative of the geotechnical conditions of Baghdad were used. The samples were collected from areas experiencing active construction and documented settlement issues. Ten samples were selected to be representative of the most critical geotechnical zones within the urban extent of Baghdad, but not the entire governorate. The selected area portrays the typical conditions faced in foundation and infrastructure works throughout the city. The spatial distribution of the sampling locations is shown in Figure 1. A typical soil sample is displayed in Figure 2.

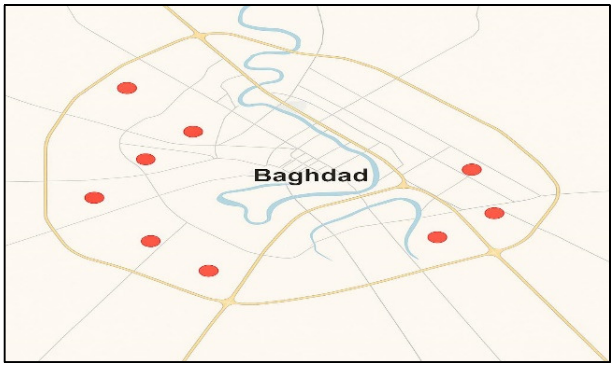

Fig. 1. Spatial distribution of soil and sampling locations in Baghdad.

Fig. 2. The clayey soil used in this study.

The data consisted of critical physical and engineering characteristics concerning the soil settlement, such as:

- The water content, which is approximately 35%.
- The Atterberg limits, liquid and plastic, which are close to 40% and 23%, respectively.
- The dry density, which usually is close to 1.6 g/cm^3.
- The permeability coefficient, with typical values around 1.4×10^{-7}.
- The consolidation tests, which are used to measure the settlement rate.

B. Laboratory Testing Program

A comprehensive laboratory testing program was implemented to determine the physical and mechanical properties of the collected soil samples. The following standard tests were conducted in accordance with the ASTM and BS procedures:

- Natural water content. It is determined using oven-drying methods to assess the initial moisture conditions of the clay samples.
- Atterberg limits (liquid and plastic limits). It is used to evaluate the plasticity characteristics of the soil and classify its behavior under varying moisture conditions.
- Dry density. It is measured by compacting the soil in a standard mold and calculating the mass per unit volume after drying, following conventional procedures.
- Permeability (falling head method). The coefficient of permeability is determined to assess the water movement through the clay matrix, which is a key factor influencing the consolidation and settlement.
- One-dimensional consolidation test (oedometer test). It is conducted to measure the settlement under incremental vertical loads. This test provides key data on the compressibility, coefficient of consolidation, and pre-consolidation pressure.

C. Data Analysis

The settlement values were derived from consolidation (oedometer) tests, and the other parameters were measured in accordance with standard laboratory procedures. Each soil parameter was statistically analyzed to evaluate its influence on the settlement behavior. The variation in settlement was compared with the corresponding changes in the water content, plasticity index, dry density, and permeability. Graphical interpretations (e.g., scatter plots and correlation matrices) were prepared to identify the trends and relationships among the variables.

III. RESULTS

A. Overview of Laboratory Results

Table I presents the geotechnical properties of ten representative clayey soil samples collected from various locations within Baghdad. These samples reflect the typical subsurface conditions encountered in the city, including moderate to high water content and plasticity. Laboratory tests were conducted to measure the water content, liquid limit, plastic limit, dry density, permeability, and corresponding one-dimensional settlement under the applied loads.

As depicted in Table I, the water content across the ten samples ranged from 34.5% to 36.3%, reflecting relatively consistent but slightly fluctuating moisture levels across the sampled sites. The dry density varied between 1.55 and 1.62 g/cm^3. The liquid limit values were close to 40%, indicating moderate to high plasticity levels typical of the clayey soils in the Baghdad region. The plastic limit was found close to 24%. These values are important for classifying the soils according to their plasticity behavior. The permeability values were consistently low (on the order of 10^{-7} cm/s), which aligns with the known behavior of fine-grained soils in Baghdad. The settlement observed during the oedometer tests ranged between 8.2 mm and 9.2 mm, reflecting the moderate compressibility characteristics of the soils under investigation.

TABLE I. SOIL PROPERTIES AND SETTLEMENT RESULTS

Sample no.	Water content (%)	Liquid limit (%)	Plastic limit (%)	Dry density (g/cm³)	Permeability coefficient (cm/s)	Settlement (mm)
1	35.1	40.2	23.4	1.58	1.4×10^{-7}	8.7
2	34.8	38.9	22.8	1.6	1.5×10^{-7}	8.4
3	36.3	42.5	24.6	1.55	1.3×10^{-7}	9.1
4	35.7	41.1	23.9	1.57	1.4×10^{-7}	8.8
5	34.5	39.5	22.5	1.61	1.6×10^{-7}	8.2
6	36	41.7	24.1	1.56	1.3×10^{-7}	9
7	35.2	40	23.2	1.59	1.4×10^{-7}	8.5
8	34.9	39.1	22.7	1.62	1.5×10^{-7}	8.3
9	36.1	41.9	24.3	1.55	1.3×10^{-7}	9.2
10	35.6	40.8	23.6	1.58	1.4×10^{-7}	8.6

B. Effect of Water Content on Settlement

A positive correlation was observed between the water content and settlement, as shown in Figure 3. Higher water content generally resulted in greater settlement. This trend indicates that the increased moisture reduces the inter-particle bonding and enhances the compressibility under loading. The sample with the highest water content (36.3%) showed one of the highest settlements (9.1 mm), whereas the lowest water content (34.5%) was associated with the lowest settlement (8.2 mm).

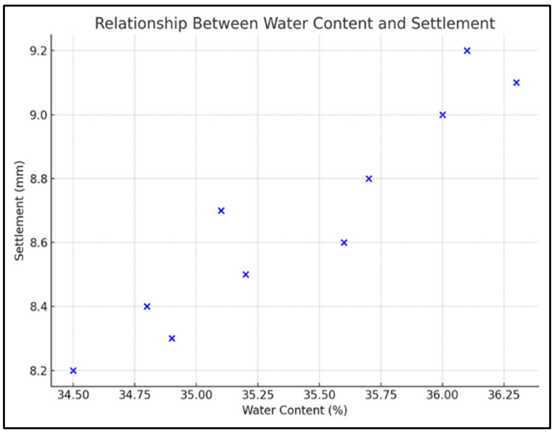

Fig. 3. Relationship between water content and settlement.

C. Effect of Dry Density on Settlement

An inverse relationship was observed between the dry density and settlement (Figure 4). The samples with higher dry density exhibited reduced settlement, indicating that denser soil structures resist compression more effectively.

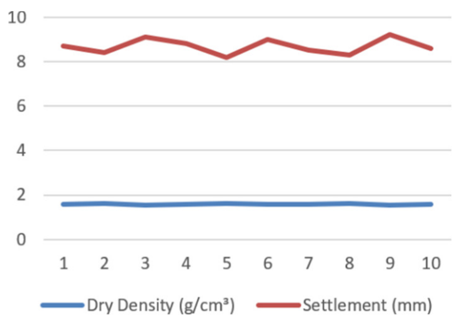

Fig. 4. Relationship between dry density and settlement.

D. Correlation Analysis

A correlation matrix was generated to examine the statistical relationships between the various geotechnical parameters. The water content exhibited a strong positive correlation with settlement, whereas the dry density exhibited a strong negative correlation. The plasticity limits also had moderate correlations with settlement, suggesting their influence on the deformation behavior. In addition to the correlation matrix, a dry semi-quantitative analysis was conducted to assess the relationships in question. The water content was noted in regard to the settlement, and the regression equation extracted was:

$$\text{Settlement (mm)} = 0.92 \times \text{Water content (\%)} - 23.5$$

The coefficient of determination (R^2) was 0.78, while still maintaining a strong positive relationship. In the same manner, a regression with dry density and settlement showed a positive correlation albeit with a decreased R^2 value of 0.71. These methods confirm the dominant relationship between the water content and dry density on the soil compressibility under load.

E. Practical Implications

The results highlight that the water content and dry density are the most influential factors affecting the settlement in the studied clayey soils. This implies that the construction strategies should focus on the moisture control and sufficient compaction. The low permeability values suggest extended consolidation times, which must be considered in design and construction planning, particularly for structures requiring rapid load application. Authors in [13, 14] provided settlement results in the range of 8–10 mm, which are similar to the present study's results, confirming the moderate compressibility of Baghdad's clayey soils. However, in this study, the water content and dry density were found to be more economically significant. This may be because the testing was performed in different seasons along with a more local capture sampling framework.

IV. CONCLUSIONS

This study investigated the settlement behavior of the clayey soils in Baghdad using a series of laboratory tests on ten representative samples collected from different urban sites. The analysis focused on correlating the soil properties, including water content, Atterberg limits, dry density, permeability, and consolidation behavior, with the measured settlement under applied loads. The findings confirm that the water content and dry density are the most influential parameters affecting the settlement. Higher moisture levels increased compressibility, whereas higher dry density reduced it. The tested soils demonstrated very low permeability, consistent with the known fine-grained subsurface conditions of Baghdad, which also implies a prolonged consolidation behavior. In comparison with previous research, such as [13, 14], the settlement values obtained in this study align with the reported ranges (8.2 mm to 9.2 mm). However, unlike previous studies that emphasized the liquid and plastic limits, this study demonstrated that the water content and dry density are more reliable predictors of the settlement behavior under field-like conditions.

Based on these findings, the engineers working in Baghdad and similar environments are advised to maintain close control of the water content during construction, ensure proper compaction to achieve higher dry densities, and allow sufficient time for primary consolidation. In areas with soft, highly plastic clays, soil improvement techniques, such as preloading and vertical drains, may be beneficial.

Future research should focus on the field validation of lab-based settlement predictions, investigation of chemical and mechanical stabilization methods, and modeling of long-term deformation behaviors under changing groundwater conditions. Such research would improve the urban planning integration and help mitigate the geotechnical risks in rapidly expanding cities like Baghdad.

ACKNOWLEDGEMENTS

The author would like to express their profound appreciation to the University of Al Maarif for its financial support. The research-related tasks were made easier due to this financial support. These resources were essential to successfully completing the present research. The grant: ID-DCS – 412

REFERENCES

[1] K. Terzaghi, *Theoretical Soil Mechanics*. John Wiley & Sons, Inc., 1943.

[2] A. U. Uzer, "Accurate Prediction of Compression Index of Normally Consolidated Soils Using Artificial Neural Networks," *Buildings*, vol. 14, no. 9, Sep. 2024, Art. no. 2688, https://doi.org/10.3390/buildings14092688.

[3] S. Lee, J. Kang, J. Kim, W. Baek, and H. Yoon, "A Study on Developing a Model for Predicting the Compression Index of the South Coast Clay of Korea Using Statistical Analysis and Machine Learning Techniques," *Applied Sciences*, vol. 14, no. 3, Jan. 2024, Art. no. 952, https://doi.org/10.3390/app14030952.

[4] S. Z. Jassim and T. Buday, *The Geology of Iraq*. Prague and Moravian Museum, Brno: Dolin, 2006.

[5] B. Das and K. Sobhan, *Principles of Geotechnical Engineering*. USA: Cengage Learning, 2013.

[6] L. Zhao, S. B. Wilson, N. Van Thieu, J. Zhou, C. Romulus, and T. T. Tran, "A new intelligence model for evaluating clay compressibility in soft ground improvement: a combined approach of bees optimization and extreme learning machine," *Acta Geophysica*, vol. 72, no. 2, pp. 579–595, Apr. 2024, https://doi.org/10.1007/s11600-023-01194-2.

[7] S. Chatterjee, P. Sultana, J. S., and R. Ralli, "Estimation of Compression Index of Cohesive-Frictional Soil in Southwest Delhi District Using Statistical Correlations," *Journal of the Geological Society of India*, vol. 100, no. 6, pp. 841–851, Jun. 2024, https://doi.org/10.17491/jgsi/2024/173914.

[8] S. Alzabeebee and S. Keawsawasvong, "Robust models to predict the secondary compression index of fine-grained soils using multi objective evolutionary polynomial regression analysis," *Modeling Earth Systems and Environment*, vol. 10, no. 1, pp. 157–165, Feb. 2024, https://doi.org/10.1007/s40808-023-01778-3.

[9] A. T. C. Goh, "Empirical design in geotechnics using neural networks," *Géotechnique*, vol. 45, no. 4, pp. 709–714, Dec. 1995, https://doi.org/10.1680/geot.1995.45.4.709.

[10] Y. Chalabi, A. E. hadj Mimoune, S. Aissaoui, M. S. Mouaissa, and A. Brixi, "Soil Density Effects on Compressibility and Expansion Behavior," *Journal of Fundamental and Applied Sciences*, vol. 16, no. 3, pp. 229–241, Sep. 2024, https://doi.org/10.4314/jfas.1378.

[11] M. A. Shahin, M. B. Jaksa, and H. R. Maier, "Artificial Neural Network Applications in Geotechnical Engineering," *Australian Geomechanics Journal*, vol. 36, no. 1, Mar. 2001.

[12] K.-K. Phoon and F. H. Kulhawy, "Characterization of geotechnical variability," *Canadian Geotechnical Journal*, vol. 36, no. 4, pp. 612–624, Nov. 1999, https://doi.org/10.1139/t99-038.

[13] M. Zhao, J. Gu, M. H. El Naggar, H. Liu, G. Liu, and T. Wang, "Intrinsic compressibility of laterites and lateritic soils," *Canadian Geotechnical Journal*, vol. 61, no. 12, pp. 2774–2784, Dec. 2024, https://doi.org/10.1139/cgj-2023-0610.

[14] P. Schjønning and M. Lamandé, "In search of a sound scientific basis for quantification of soil precompression stress," *Soil Science Society of America Journal*, vol. 89, no. 1, 2025, Art. no. e20784, https://doi.org/10.1002/saj2.20784.

[15] J. T. Germaine and A. V. Germaine, *Geotechnical Laboratory Measurements for Engineers*. John Wiley & Sons, Inc., 2009.

[16] R. D. Holtz, W. D. Kovacs, and T. Sheahan, *Introduction to Geotechnical Engineering, An*, 2nd ed. Upper Saddle River, NJ: Pearson, 2011.

[17] K. Terzaghi, R. B. Peck, and G. Mesri, *Soil Mechanics in Engineering Practice*, 3rd ed. New York: Wiley-Interscience, 1996.

[18] J. B. Burland and M. C. Burbidge, "Settlement of Foundations on Sand and Gravel.," *Proceedings of the Institution of Civil Engineers*, vol. 78, no. 6, pp. 1325–1381, Dec. 1985, https://doi.org/10.1680/iicep.1985.1058.

[19] A. W. Skempton, "The Pore-Pressure Coefficients A and B," *Géotechnique*, vol. 4, no. 4, pp. 143–147, Dec. 1954, https://doi.org/10.1680/geot.1954.4.4.143.

[20] L. Bjerrum, "Engineering Geology of Norwegian Normally-Consolidated Marine Clays as Related to Settlements of Buildings," *Géotechnique*, vol. 17, no. 2, pp. 83–118, Jun. 1967, https://doi.org/10.1680/geot.1967.17.2.83.

[21] F. H. Chen, *Foundations on Expansive Soils*, 1st ed., vol. 12. Amsterdam, Netherlands: Elsevier, 2012.

[22] C. C. Ladd, "Stability Evaluation during Staged Construction," *Journal of Geotechnical Engineering*, vol. 117, no. 4, pp. 540–615, Apr. 1991, https://doi.org/10.1061/(ASCE)0733-9410(1991)117:4(540).

[23] M. D. Abdulnafaa, A. Y. Alshuwaykhi, and A. W. Al-Dabbagh, "Residual Shear Strength and Other Geotechnical Properties of Clay Mixed with Different Sand Ratios," *Engineering, Technology & Applied Science Research*, vol. 15, no. 2, pp. 21294–21299, Apr. 2025, https://doi.org/10.48084/etasr.9708.

[24] A. A. S. Al-Mohammedi, "Analysis of the Effects of Temperature and Treatment Duration on the Resistance of Expansive Soil Improved with Lime in Baghdad, Iraq," *Engineering, Technology & Applied Science Research*, vol. 14, no. 6, pp. 18829–18834, Dec. 2024, https://doi.org/10.48084/etasr.8850.

[25] A. A. S. Al-Mohammedi, "Evaluation of Glass Powder's Impact on the Atterberg Limits of Anbar Soil," *Engineering, Technology & Applied Science Research*, vol. 14, no. 5, pp. 17276–17279, Oct. 2024, https://doi.org/10.48084/etasr.8351.

[26] A. A. S. Al-Mohammedi and M. Seyedi, "Enhancing Geotechnical Properties of Clayey Soil with Recycled Plastic and Glass Waste," *Revue Des Composites Et Des Matériaux Avancés*, vol. 33, no. 6, pp. 363–369, Dec. 2023, https://doi.org/10.18280/rcma.330603.