Investigation the Effect of Sludge Cake and Sewage Sludge on Clay Soil Parameters: A Numerical Approach

Nemat Allah Samiei Paghaleh [1], Mohammad Reza Boroomand [*2], Mahmoud Reza Shahverdi [3]

[1]MSc Student Of Civil Engineering, Tafresh University, Tafresh, Iran

[2]Associate Professor, Department Of The Civil Engineering, Faculty Of Geotechnial Engineering, Tafresh University, Tafresh, Iran

[3]Assistant Professor, Department Of The Civil Engineering, Faculty Of Geotechnial Engineering, Tafresh University, Tafresh, Iran

ABSTRACT

This study investigates the influence of sludge cake and wastewater treatment plant effluent on the geotechnical parameters of clayey soils using a three-dimensional finite element method implemented in PLAXIS 3D software. Sixteen different scenarios were simulated, considering two curing periods (7 and 28 days) and varying sludge content percentages (0-16%). The results demonstrate that the addition of sludge cake significantly enhances the bearing capacity of the foundation, with the optimum sludge content identified as 14%. At this percentage, the bearing capacity increased by approximately 54% compared to pure clay, while the curing period exhibited negligible impact. The findings suggest that sludge cake can be effectively utilized as a soil stabilizer in geotechnical applications, offering both environmental and engineering benefits.

KEYWORDS

Sludge cake, wastewater effluent, soil improvement, bearing capacity, numerical modeling, PLAXIS 3D.

1. Introduction

The rapid growth of urbanization and population has led to increased water consumption and subsequent wastewater production, resulting in large quantities of sludge as a by-product of treatment processes. The disposal of sludge poses significant environmental challenges, including soil contamination and groundwater pollution [1-3]. Recent studies have explored the potential reuse of sludge in geotechnical applications as a sustainable alternative to traditional disposal methods [4-6].

Sludge from wastewater treatment plants has been investigated for its potential to improve soil properties. For instance, Arulrajah et al. (2013) reported that compacted sludge exhibits relatively high internal friction angles and moderate cohesion [6]. Similarly, Montalvan et al. (2019) observed that the addition of water treatment sludge (WTS) reduced cohesion but increased the internal friction angle of soil mixtures [7]. However, the effect of sludge content and curing time on the bearing capacity of the clayey soil has not been extensively studied through numerical modeling.

This research aims to fill this gap by evaluating the effect of sludge cake addition on the bearing capacity of clayey soil foundations using advanced finite element analysis. The study also examines the influence of curing time and identifies the optimal sludge content for maximum bearing capacity improvement.

2. Materials and Methods

The soil used in this study was collected from a depth of 0.5 to 1 meter in Tehran, Iran, and classified as low plasticity clay (CL) according to ASTM standards. The sludge was obtained from Shahid Mahallati wastewater treatment plant in Tehran. The chemical composition of the sludge was analyzed using ICP-MASS, confirming that all elements were within permissible limits (Table2).

[a] MSc Student, E-mail: nemat.samiei@iau.ac.ir
[*] Corresponding author, Assistant Professor, E-mail: boroomand@tafreshu.ac.ir
[b] Assistant Professor. E-mail: shahverdi@tafreshu.ac.ir

The numerical modeling was performed using PLAXIS 3D (2022), a finite element-based software widely used in geotechnical engineering. The Mohr-Coulomb constitutive model was adopted to stimulate soil behavior. The input parameters included cohesion, internal friction angle, elasticity modulus, Poisson's ratio, shear modulus, and dilation angle, all derived from laboratory tests (direct shear, unconfined compression, and chemical analysis).

Sixteen models were developed with sludge contents of 0%, 3%, 4%, 5%, 7%, 11%, 14%, 16%, and two curing periods (7 and 28 days). The foundation was modeled as a square footing with dimensions of 2.5 m × 2.5 m, resting on a 4 m thick clay layer. A very fine mesh with approximately 47,000 elements was used to ensure accuracy.

Table 1. Geotechnical properties of soil sludge mixtures for two curing periods (7 and 28 days).

Sample	Sludge Content (%)	Curing Period (days)	Internal Friction Angle (˚)	Cohesion (KPa)	Elasticity Modulus (MPa)	Poisson's Ratio
1	0	7	24.7	0.14	9.77	0.3
2	3	7	25.1	0.10	6.70	0.3
3	14	7	33.2	0.05	9.59	0.3
4	16	7	30.4	0.06	16.61	0.3
5	0	28	24.7	0.14	9.77	0.3
6	3	28	25.1	0.10	6.70	0.3
7	14	28	33.2	0.05	9.59	0.3
8	16	28	30.4	0.06	16.61	0.3

3. Results and Discussion

The numerical results indicate a consistent increase in bearing capacity with higher sludge content, regardless of the curing period. Figures 1 and 2 illustrate the load settlement curves for different sludge percentages under 7-day and 28-day curing, respectively.

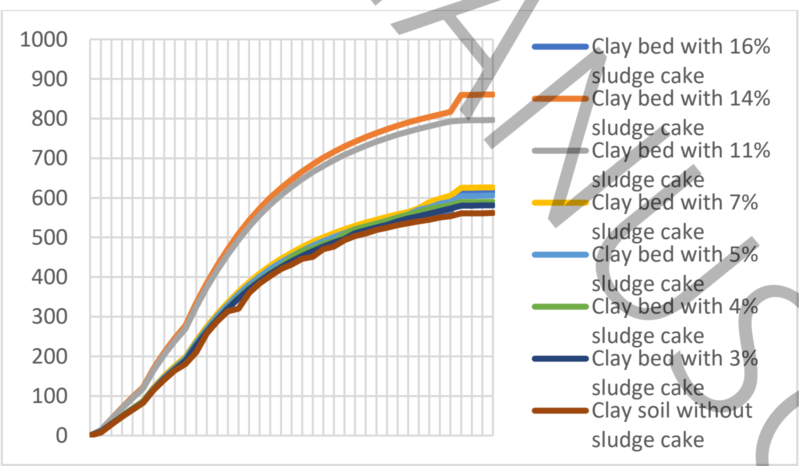

Figure 1. Bearing capacity vs. settlement for 7-day curing.

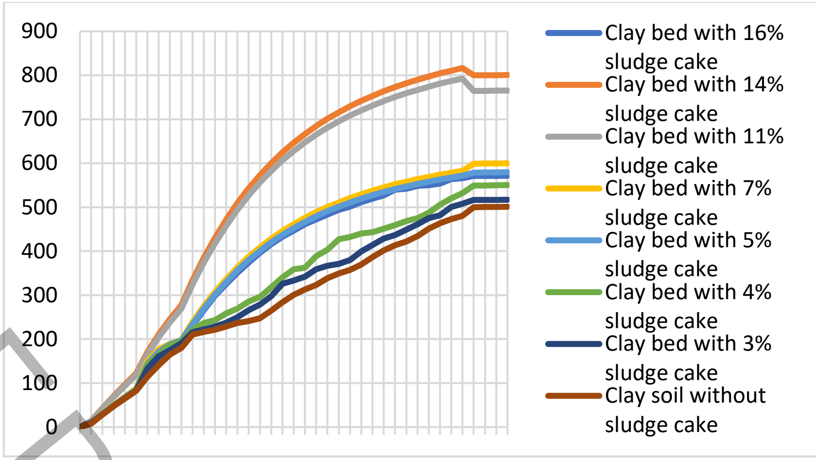

Figure 2. Bearing capacity vs. settlement for 28-day curing.

The optimum sludge content was found to be 14%, which resulted in a bearing capacity of 800 KN at 6 cm settlement, representing a 54% increase compared to pure clay. Even a small addition of 3% sludge improved the bearing capacity by 3.5%. Beyond the optimum point (16% sludge), the bearing capacity decreased but remained higher than that of pure clay.

The internal friction angle increased with sludge addition, while cohesion decreased, consistent with findings by Montalvan et al. (2019) [7]. The curing period (7 vs. 28 days) did not significantly affect the results, suggesting that chemical reactions between sludge and soil were minimal within this timeframe.

Table 2. Summary of bearing capacity improvement.

Sludge Content (%)	Bearing Capacity (KN)	Improvement (%)
0	516	-
3	534	3.5
14	800	54.0
16	560	8.5

4. Conclusion

This study demonstrates that sludge cake can effectively enhance the bearing capacity of clayey soils, with 14% identified as the optimum content. The curing period had negligible influence on the results, indicating that sludge stabilization does not require extended curing for practical applications. The use of sludge in geotechnical projects not only improves soil performance but also contributes to sustainable waste management by repurposing a problematic by-product.

The findings align with previous research on sludge reuse in geotechnics and provide a numerical basis for its application in foundation engineering. Future studies could explore the long-term durability and environmental impacts of sludge-stabilized soils under field conditions.

5. References

[1] R. Lai, Diggingdeeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems, Global Change Biology, 24(8) (2018) 3285–3301.
[2] R. Lai, Soil carbon sequestration to mitigate climate change Geoderma, 123(1-2) (2004) 1–22.
[3] S.R. Carpenter, DeFries, T., Mooney, H. A., Polasky, S., Reid, W. V., & Scholes, R. J., Millennium Ecosystem Assessment: Reseach needs, Science, 314(5797) (2006) 257–258.
[4] C. Xu, Chen, W., & Hong, J., Life-cycle environmental and economic assessment of sewage sludge treatment in China, Journal of Cleaner Production 67 (2014) 79–87.
[5] B.C. O'Kelly, Geotechnics of municipal sludges and residues for landfilling Geotechnical Research, 3(4) (2016) 148–179.
[6] A. Arulrajah, Piratheepan, J., Disfani, M. M., & Bo, M. W., Geotechnical and geoenvironmental properties of recycled construction and demolition materials in pavement subbase applications, Journal of Materials in Civil Engineering 25(8) (2013) 1077–1088.
[7] E.L. Montalvan, & Boscov, M. E. G., Geotechnical characterization of a soil-water treatment sludge mixture, Geo-Chicago 2016, (2016) 418–427.