

Empirical Correlation Between Geophysical and Geotechnical Parameters of Pleistocene Madhupur Clay in Dhaka, Bangladesh

Saba Karim¹, Farhad Hossain¹, and A.S.M. Woobaidullah^{1*}

¹Department of Geology, University of Dhaka, Dhaka-1000, Bangladesh

(*Corresponding E-mail: woobaid.du@gmail.com)

Received: July 31, 2025, Accepted: September 12, 2025

Abstract: This study investigates the potential for correlating geophysical and geotechnical parameters of the Pleistocene Madhupur Clay formation in Dhaka, Bangladesh. Due to rapid urban expansion and infrastructure development, there is a growing need for efficient subsurface characterization. Traditional geotechnical methods, though reliable, are expensive and limited in spatial coverage. Geophysical methods such as Electrical Resistivity Tomography (ERT) and Multichannel Analysis of Surface Waves (MASW) offer non-invasive, cost-effective alternatives. Fifteen ERT and MASW surveys were conducted at key locations across Dhaka. Five Standard Penetration Test (SPT) boreholes were used for ground-truthing. Laboratory analysis of soil samples focused on moisture content, Atterberg limits, unit weight, unconfined compressive strength (UCS), and consolidation behavior. Regression analysis revealed strong correlations between resistivity and SPT-N values ($R^2 = 0.69$), resistivity and moisture content ($R^2 = 0.74$), shear wave velocity and unit weight ($R^2 = 0.79$), and Vs and UCS ($R^2 = 0.64$). These results support the use of ERT and MASW as effective proxies for estimating subsurface properties in complex urban environments dominated by Madhupur Clay.

Keywords: Madhupur clay, ERT, MASW, Shear wave velocity, SPT, UCS, Soil correlation.

Introduction

The subsurface of Dhaka city is primarily composed of the Pleistocene Madhupur Clay, known for its stiff, over-consolidated, and highly plastic characteristics. These soils pose serious geotechnical challenges due to their high variability in moisture content, strength, and compressibility. Traditional methods of assessing soil behavior, such as borehole drilling and lab testing, are often cost-prohibitive, time-consuming, and spatially sparse in urban environments.

As an alternative, geophysical methods such as Electrical Resistivity Tomography (ERT) and Multichannel Analysis of Surface Waves (MASW) are gaining popularity for preliminary site investigation (Hussien and Karray, 2015; Sudha et al., 2009). However, the reliability of these techniques depends heavily on establishing local empirical correlations with standard geotechnical parameters. In Bangladesh, few

studies have attempted to quantify such correlations for Madhupur Clay. This study bridges that gap by establishing empirical models linking resistivity and shear wave velocity (Vs) with parameters such as SPT-N, UCS, unit weight, and moisture content.

Methodology

Field investigations were carried out at 15 sites across Dhaka. Two geophysical methods were used:

Electrical resistivity tomography (ERT)

Wenner (α) array was used to measure apparent resistivity (ρ_a). The basic equation for resistivity is:

$$\rho_a = R \cdot \frac{A}{L}$$

Where ρ_a = resistivity ($\Omega\cdot m$), R = resistance (Ω), A = cross-sectional area of the current path (m^2) and L = electrode spacing (m).

The ERT profiles were processed using RES2DINV software through nonlinear least-squares inversion to generate true resistivity sections.

Shear wave velocity (MASW)

The shear wave velocity (Vs) was derived from the fundamental Rayleigh wave dispersion curve. Vs is related to shear modulus G and soil density ρ by:

$$G = \rho \cdot V_s^2$$

Where G = shear modulus (Pa), ρ = soil density (kg/m^3) and V_s = shear wave velocity (m/s).

MASW data were processed using GEOMATRIX software. Inversion of dispersion curves produced Vs-depth profiles up to 30 meters.

Geotechnical investigation:

At five locations, SPT was performed and both disturbed and undisturbed samples were collected. Laboratory tests included:

- Moisture content (ASTM D2216)
- Atterberg limits (ASTM D4318)

- Unit weight (ASTM D7263)
- UCS (ASTM D2166)
- Oedometer test for compression index (C_c) and swelling index (C_s)

Regression equations were developed to relate geophysical measurements to geotechnical properties, such as:

$$V_s = 97.55 \cdot N^{0.341}$$

$$V_s = 87.34 \cdot \gamma - 940.5$$

Where N = SPT blow count and γ = unit weight (kN/m^3).

Results and discussions

The ERT surveys revealed that Madhupur Clay typically exhibits resistivity values ranging from 15 to 40 $\Omega\text{-m}$. Resistivity showed a moderate positive linear correlation with SPT-N values ($R^2=0.69$) and shear wave velocity showed slight ($R^2=0.63$, Figure 1). These trends reflect the influence of pore water and compaction on electrical conductivity, aligning well with existing literature on clayey soils.

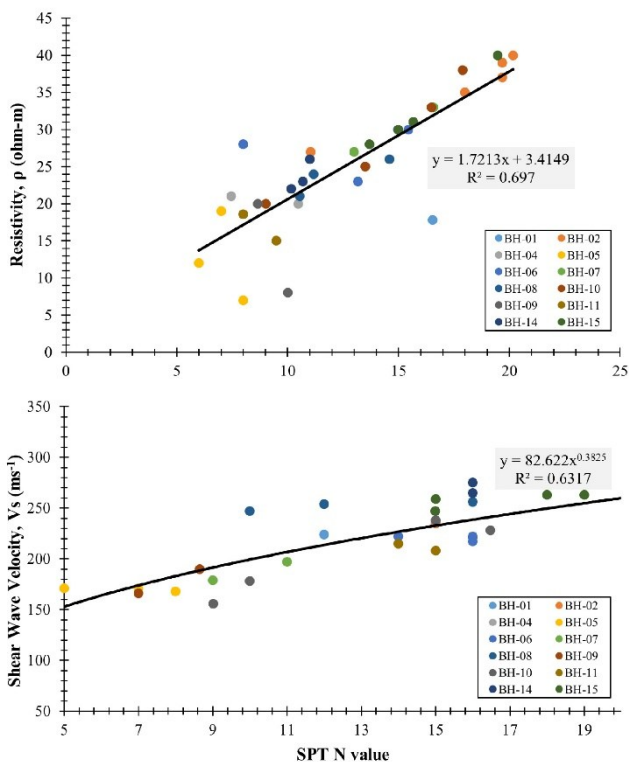


Figure 1, Correlation between SPT N-value with apparent resistivity and shear wave velocity.

MASW-derived shear wave velocities (V_s) ranged between 150–530 m/s, increasing with depth and material stiffness. Empirical correlations between V_s and key geotechnical parameters were statistically significant:

With SPT-N: $V_s = 97.55 \cdot N^{0.341}$ ($R^2=0.64$)

With unit weight: $V_s = 87.34 \cdot \gamma - 940.5$ ($R^2=0.79$)

With UCS: $V_s = 3.52 \cdot \sigma_c + 179.8$ ($R^2=0.64$)

These relationships confirm that V_s is sensitive to soil stiffness and density and can serve as a reliable proxy for subsurface strength assessments in cohesive soils.

Laboratory tests further showed that Madhupur Clay is highly plastic (PI up to 66%), over-consolidated (OCR up to 14.5), and compositionally dominated by silt and clay (>85%). These conditions explain the observed variability in resistivity and V_s across sites.

In summary, the results affirm that ERT and MASW can meaningfully predict geotechnical behavior, particularly in spatially variable, fine-grained soils like Madhupur Clay.

Conclusion

This study demonstrates that geophysical methods such as ERT and MASW can be effectively correlated with key geotechnical parameters of Madhupur Clay. The established empirical equations can support faster, cost-effective site investigations in urban areas. This integrated approach reduces reliance on intrusive testing and offers a sustainable model for geotechnical site characterization in similar Pleistocene clay environments.

Acknowledgment

The authors would like to thank the University Grants Commission (UGC), Bangladesh for the research grant to conduct this study and the Urban Resilience Project (RAJUK) for borehole datasets. Thanks also to the Engineering Geology Laboratory team of University of Dhaka for technical assistance.

References

Hussien, M. N., and Karray, M. (2015). Shear wave velocity as a geotechnical parameter: An overview. *Canadian Geotechnical Journal*, 53(2), 252–272. <https://doi.org/10.1139/cgj-2014-0524>

Sudha, K., Israil, M., Mittal, S., and Rai, J. (2009). Soil characterization using electrical resistivity tomography and geotechnical investigations. *Journal of Applied Geophysics*, 67, 74–79. <https://doi.org/10.1016/j.jappgeo.2008.09.012>