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Original Paper

Assessing Subsurface Conditions for Tower Foundations: A Comparison of In-situ Standard Penetration Test (SPT), Cone Penetration Test (CPT), and Vertical Electrical Sounding (VES) Methods

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Abstract

Accurate soil stratigraphy is paramount for designing stable, reliable tower foundations for transmission lines. Difficult terrain often makes conventional field testing, such as the Standard Penetration Test (SPT) and Cone Penetration Test (CPT), impractical due to accessibility issues and high costs. This research applies Vertical Electrical Sounding (VES) alongside **SPT** and **CPT** to validate and compare their efficacy in obtaining subsurface profiles. **VES** (ASTM D6431) offers a non-invasive, cost-effective alternative that detects subsurface resistivity variations to identify soil and rock layers. The study establishes correlations between **SPT**, **CPT**, and **VES** results, providing insights into their interchangeability under varying site conditions. **SPT** (ASTM D1586), **CPT** (ASTM D5778), and **VES** (Miller 400D resistivity meter) tests were conducted at multiple tower locations. Key findings reveal **VES** accurately determines bedrock presence and continuity where **SPT** and **CPT** encounter refusal. Bearing strength values from **CPT** and **SPT** correlate closely, and **VES** results align with **SPT**, confirming consistent lithology. This research highlights **VES** as a valuable tool for geotechnical investigations in challenging environments.

1. Introduction

Soil stratigraphy, the study of subsurface layers, is fundamental in geotechnical engineering for crucial applications like foundation design and slope stability, helping to prevent failures and optimize costs. **Tower foundations** are critical components whose stability depends heavily on the underlying soil stratigraphy. Geotechnical investigations employ various field testing methods to assess soil and rock properties. Among the most prominent are the Standard Penetration Test (SPT), Cone Penetration Test (CPT), and Vertical Electrical Sounding (VES), each selected based on specific site conditions and project requirements.

2. Methodology/Field Setup

2.1 Equipment Description

2.1.1 The SPT Assemblage

Standard Penetration Testing (SPT) was conducted in accordance with ASTM D 1586 using a drill rig equipped with a split-barrel sampler.

2.1.2 The CPT Equipment

Cone Penetration Testing (CPT) was performed using a CPT machine (ASTM D 5778). The CPT probe incorporated a 60-degree conical tip, a friction sleeve, and a porous element to measure bearing pressure, side friction, and pore water pressure, respectively.

2.1.3 The VES Equipment

Soil and rock electrical resistivity was measured using a Miller 400D resistivity meter via the Wenner Four-Electrode Method (ASTM D 6431), utilizing the necessary electrodes and testing gear.

2.2 Test Procedures

2.2.1 The Standard Penetration Testing

SPT was conducted on angle tower locations to a maximum depth of 15m. Due to the hard granitic rock encountered, achieving the specified 3m of rock coring was difficult. **VES** technology was employed in these cases to determine bedrock continuity to the 15m target depth.

2.2.2 The Cone Penetration (CPTu) Testing

CPT was performed on suspension tower locations to a 15m target depth at a rate of 0.8-1.2 m/min. As with the **SPT**, **VES** was used upon refusal to determine subsurface nature. Data was collected via a digital acquisition system.

2.2.3 The VES Testing

The Wenner Four-Electrode Method was used as it is quick and simple. Voltage was applied between outer electrodes and measured between inner electrodes to obtain resistivity values. Electrode spacing was calibrated to achieve the required target depth.

2.2.4 Laboratory Test

Soil samples collected from **SPT** and **CPT** boreholes underwent standard laboratory analyses including moisture content determination, Atterberg limits, and classification according to the USCS system. **VES** data was processed using '1D - Earth Imager' software to derive parameters like allowable bearing capacity and unit weight.

3. Results and Discussions

3.1 Validation and Comparison of SPT and VES Results

Validation exercises were conducted at three locations (BH17, BH23, BH54) where initial **SPT** refusal occurred at shallow depths, preventing investigation to the target 15m depth. Across all three sites, **VES** testing was highly effective in determining the nature and continuity of the subsurface where the drill rig encountered refusal. The resistivity values obtained by **VES** clearly identified the boundaries between soil layers and the underlying granitic bedrock. The material descriptions and depths of layers identified by both methods correlated well, confirming a consistent lithology at all locations. This demonstrated that **VES** provides a reliable, non-invasive alternative for identifying bedrock presence and continuity to greater depths in challenging environments.

3.2 Validation and Comparison of SPT and CPT Results

SPT and **CPT** methods were validated and compared at two tower locations (BH58 and BH32). The primary design parameters derived from the two test methods showed a close correlation across different founding depths.

Specifically, the allowable bearing capacity, soil density, and angle of repose values were consistent between both methods. For instance, at the 4m founding depth for BH58, both methods yielded comparable results for these parameters, which consistently led to a classification within the same S3 soil category. These results reinforce that the two conventional methods produce comparable engineering properties for foundation design when performed in the same soil types.

Table 1. Summary of SPT and VES Results at Refusal Depths

Borehole (BH ID)	**SPT Refusal Depth (m)**	**SPT Material Description**	**VES Log (m)**	**VES Material Confirmation**	**Allowable Bearing Capacity (MPa)**	**RQD (%)**
BH17	3.0	Moderately weathered granitic bedrock	3.0 – 4.0	Moderately weathered granitic bedrock	5.5 (p. 7)	65
BH23	3.5	Moderately weathered granitic bedrock	3.5 – 4.0	Moderately weathered granitic bedrock	5.5 (p. 13)	60
BH54	6.6	Moderately weathered granitic bedrock	6.6 – 8.0	Moderately weathered granitic bedrock	5.5 (p. 20)	65

Table 2. Summary of Key Design Parameters for SPT and CPT Correlations

Borehole (BH ID)	**Depth (m)**	**Method**	**Allowable Bearing Capacity (MPa)**	**Soil Density (Kg/m3cubed3)**	**Angle of Internal Friction (composed with)**
BH58	4.0	SPT	0.26 (p. 25)	1808 (p. 25)	33.5
BH58	4.0	CPT	0.27 (p. 26)	1792 (p. 26)	31
BH32	4.0	SPT	0.31 (p. 28)	1920 (p. 28)	35.5
BH32	4.0	CPT	0.44 (p. 29)	1800 (p. 29)	31

Table 3. Comparison of Field Testing Method Characteristics

Characteristic	**Standard Penetration Test (SPT)**	**Cone Penetration Test (CPT)**	**Vertical Electrical Sounding (VES)**
Data Type	Discrete points	Continuous profile	Continuous profile (geophysical)
Sample Collection	Yes (disturbed sample)	No sample collected	Non-invasive, no sample
Data Accuracy	Less accurate, operator dependent	Highly accurate, real-time data	Good for detecting layer continuity
Suitability	Granular soils (sands, gravels)	Soft clays, silts, sands	Challenging/inaccessible terrain

4. Conclusion and Recommendations

4.1 Conclusion

The study successfully established that the lithology and material descriptions obtained from **VES** technology correlate well with those obtained from **SPT** sampling. **VES** proved capable of accurately determining the presence and continuity of bedrock beyond the refusal depths encountered by conventional methods.

Furthermore, key design parameters (allowable bearing capacity, soil density, and angle of repose) derived from both **CPT** and **SPT** correlations produced consistent results, falling within the same soil categories across different locations. This confirms the reliability and interchangeability of the methods under these specific site conditions.

4.2 Recommendations

Based on the findings, the following are recommended:

- **Employ VES** as a primary, cost-effective method for initial soil stratigraphy investigations in areas where drill rigs face access limitations.
- **Integrate all three methods** (**SPT**, **CPT**, and **VES**) in critical project areas to leverage their combined strengths, validate data, and ensure a comprehensive understanding of subsurface conditions for robust foundation design.

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