Scientific Research Publishing

International Journal of Geosciences, 2023, 14, 840-854
https://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

Obtaining 2D Soil Resistance Profiles from the Integration of Electrical Resistivity Data and Standard Penetration Test (SPT) and Light Dynamic Penetrometer (DPL) Resistance Tests—Applications in Mass Movements Studies

Cassiano Antonio Bortolozo[1,2*], Tatiana Sussel Gonçalves Mendes[1], Mariana Ferreira Benessiuti Motta[3], Silvio Jorge Coelho Simões[1], Tristan Pryer[4], Daniel Metodiev[2], Marcio Roberto Magalhães de Andrade[2], Maiconn Vinicius de Moraes[1], Danielle Silva de Paula[2], Nélio José Bastos[5], Luana Albertani Pampuch[1], Rodolfo Moreda Mendes[2], Marcio Augusto Ernesto de Moraes[2]

[1]Institute of Science and Technology, São Paulo State University (Unesp), São José dos Campos, Brazil
[2]Cemaden—National Center for Monitoring and Early Warning of Natural Disasters, General Coordination of Research and Development, São José dos Campos, Brazil
[3]Faculty of Engineering and Sciences, Department of Civil Engineering, São Paulo State University (Unesp), Guaratinguetá, Brazil
[4]Department of Mathematical Sciences, University of Bath, Bath, UK
[5]Department of Geotechnical Engineering, University of Sao Paulo, Sao Carlos, Brazil
Email: *cassianoab@gmail.com

How to cite this paper: Bortolozo, C.A., Mendes, T.S.G., Motta, M.F.B., Simões, S.J.C., Pryer, T., Metodiev, D., de Andrade, M.R.M., de Moraes, M.V., de Paula, D.S., Bastos, N.J., Pampuch, L.A., Mendes, R.M. and de Moraes, M.A.E. (2023) Obtaining 2D Soil Resistance Profiles from the Integration of Electrical Resistivity Data and Standard Penetration Test (SPT) and Light Dynamic Penetrometer (DPL) Resistance Tests—Applications in Mass Movements Studies. *International Journal of Geosciences*, **14**, 840-854.
https://doi.org/10.4236/ijg.2023.149045

Received: July 28, 2023
Accepted: September 12, 2023
Published: September 15, 2023

Abstract

In Brazil and various regions globally, the initiation of landslides is frequently associated with rainfall; yet the spatial arrangement of geological structures and stratification considerably influences landslide occurrences. The multifaceted nature of these influences makes the surveillance of mass movements a highly intricate task, requiring an understanding of numerous interdependent variables. Recent years have seen an emergence in scholarly research aimed at integrating geophysical and geotechnical methodologies. The conjoint examination of geophysical and geotechnical data offers an enhanced perspective into subsurface structures. Within this work, a methodology is proposed for the synchronous analysis of electrical resistivity geophysical data and geotechnical data, specifically those extracted from the Light Dynamic Penetrometer (DPL) and Standard Penetration Test (SPT). This study involved a linear fitting process to correlate resistivity with N10/SPT N-values from DPL/SPT soundings, culminating in a 2D profile of N10/SPT N-values predicated on electrical profiles. The findings of this research furnish invaluable insights into slope stability by allowing for a two-dimensional representation of penetration resistance properties. Through the synthesis of geophysical and geotechnical data, this project aims to augment the comprehension of subsurface conditions, with potential implications for refining landslide risk evaluations. This endeavor offers insight into the formulation of more effective and precise slope management protocols and disaster prevention strategies.

Keywords

Geophysics, Geotechnical Data, Electrical Resistivity Method, Standard Penetration Test (SPT), Light Dynamic Penetrometer (DPL), Mass Movements

1. Introduction

In Brazil, as well as in other parts of the world, while many landslide events are triggered by rainfall, the distribution of geological structures and layers plays a fundamental role in landslide occurrence. This complexity makes the monitoring of mass movements extremely challenging, as the processes leading to landslides are intricate and dependent on numerous variables for a comprehensive understanding. Consequently, extensive research has focused on integrating geophysical and geotechnical methods [1]-[10] and utilizing registered software tools [11]-[17] to address these challenges.

In geotechnical studies, direct methods for site investigations are more widespread. These methods include boring boreholes, taking undisturbed and/or disturbed samples, and conducting field and laboratory tests. In general, these techniques involve punctual analyzes along the depth and are used to determine soil parameters.

In order to have a complete understanding of the dynamics involved in mass movements, the use of indirect methods, such as geophysical investigation, is advantageous. These methods provide a spatial distribution of the subsurface and, in combination with direct methods, can be used to estimate the soil parameters in a faster way, eliminating the limitations of both methods. [3] [4] [5] [6] used the results of geophysical tests to improve the interpretation of the geological-geotechnical profile of a mass movement. Overall, the data obtained allowed well definition of the instability zone depth.

Evaluating the Standard Penetration Test (SPT) associated with geophysical investigations, [1] emphasizes that the electrical resistivity tomography method showed great potential for extrapolating data from SPT surveys, remedying the deficiency in the complete structural characterization in civil engineering projects. [8] obtained a strong correlation between NSPT values and electrical resistivity, which indicates that variations in the electrical resistivity of soil are directly related to soil stiffness. [10] identified a linear correlation between electrical resistivity and NSPT in the investigation of a bridge foundation site. The correlation performed from the simple linear regression showed that the fitted linear slopes were influenced by the lithology and the clay content.

Within this framework, the present project introduces the development of a methodology designed for the collaborative analysis of geophysical data, derived from electrical resistivity surveys, and information from the Light Dynamic Penetrometer (DPL) and Standard Penetration Test (SPT). The combination of geophysical and geotechnical data aspires to afford exhaustive insights into slope behavior and the underlying mechanisms precipitating mass movements. This integrative approach anticipates contributing to the refinement of landslide risk assessments and the bolstering of readiness for potential hazards, thereby elevating safety protocols and decision-making in the administration of landslide-susceptible zones such as those in Campos do Jordão. Such advancements are instrumental in augmenting our comprehension of mass movement processes and enriching the knowledge possessed by the Cemaden Operational Room operators monitoring the slopes. The specific area of focus for this project is Campos do Jordão, identified as one of the critical regions with available geotechnical data.

2. Study Area—Campo do Jordão/SP

Campos do Jordão, situated in the state of São Paulo, is a high-altitude municipality beleaguered by multiple landslide-prone regions. The city's tropical locale, aggravated by impromptu urban expansion, has induced geological vulnerabilities, heightening its susceptibility to landslides. Anthropogenic activities, compounded by the region's intense rainfall, contribute to slope instability. A synergistic effect of soil characteristics, water pore pressure, vegetative cover, and climatic conditions cultivate an environment with pronounced landslide potential. Urban growth acceleration has augmented the risk, primarily driven by construction activities and alterations in soil conditions via excavation and embankments. A total of 97 events between 1999 and 2013, inclusive of 51 landslides across 43 city districts, have motivated the compilation of an extensive disaster database. The intersection of geographic factors, climatic conditions, and urbanization dilemmas necessitates vigilant landslide monitoring and risk assessment to preserve the welfare and safety of Campos do Jordão's populace. An anticipatory strategy is essential for efficacious disaster management and preclusion within the region.

In the municipality, surveys were conducted at two proximate locations, separated by less than 500 m in the Vila Britânia neighborhood (**Figure 1(a)**). Study Site 1 encompassed an Electrical Resistivity Tomography (ERT) profile extending 17.75 m, coupled with three survey points employing the Light Dynamic Penetrometer (DPL) method, reaching depths of up to 3 m at 10 cm intervals along the profile line (**Figure 1(b)**). Conversely, Study Site 2 involved an ERT of 170 m, supplemented by a Standard Penetration Test (SPT) sounding (**Figure 1(c)**).

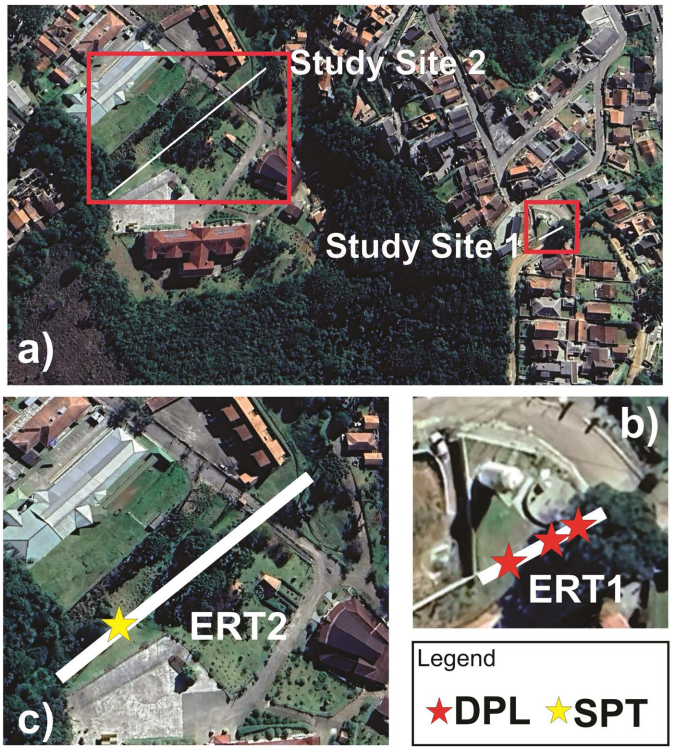

Figure 1. Geophysical and geotechnical survey sites are depicted for the Vila Britânia neighborhood in Campos do Jordão (a), with zoom views of Study Site 1 (b) and Study Site 2 (c).

3. Geotechnical Methods: DPL and SPT

Among the vital instruments for evaluating landslides, Geotechnical Investigations stand out prominently, encompassing both field tests and laboratory experiments. These investigations yield precise data and ascertain soil characteristics across the designated study area. Although widely applied and characterized by reliable results, these methods do carry certain disadvantages, such as being destructive, necessitating ground boring, and being restricted to specific points [8].

The Dynamic Penetrometer Light (DPL), as modified by [18], is a tool renowned for its simplicity and lightweight design, conferring exceptional mobility. According to [19], the DPL test yields results in the form of the number of blows required for every 10 cm of penetration. These values, which vary with depth, indicate soil strength along the profile, analogous to the interpretation provided by the Standard Penetration Test (SPT).

In comparison to other field tests, the DPL is advantageous for its ease of transport and its suitability for installation in confined spaces. Moreover, it is recognized for being environmentally benign. Unlike a sampler, the DPL cone is solid, excluding the containment of air, water, or soil, thereby facilitating an objective resistance measurement [19].

In the current study, the field test was conducted with some variations from the procedure recommended by [20]. Specifically, the test was initiated without a predrilled hole, measuring 12 cm in depth and 5 cm in diameter. The DPL was assembled and aligned using a polyurethane cushion. A metal clamp affixed to a rubber placed on the surface of the guide rod ensured a consistent drop height for the hammer, limiting the drop to a maximum of 50 cm. The DPL was driven to a depth of 3 meters, with the number of blows counted every 10 cm of driving, denoted as N10.

The Standard Penetration Test (SPT), a common in-situ test within Geotechnical Investigations, serves to delineate soil layers, pinpoint water level positions, and obtain the N value, representing the cumulative number of blows required for 0.3 meters of penetration. The test involves driving a split-barrel sampler at the base of the borehole to procure a representative, though disturbed, soil sample for identification purposes and to measure the soil's resistance to sampler penetration [21].

In geotechnical studies, the NSPT value is used as an indicator of soil shear strength and stiffness. Although some deficiencies, SPT is the most dominant in-situ test for soil investigation in Brazil and many other countries in South America [1].

Within the framework of this study, three Dynamic Penetrometer Light (DPL) surveys were conducted, reaching depths of up to 3 meters along the corresponding geophysical profile (**Figure 2(a)**). Concurrently, the Standard Penetration Test (SPT) was performed until a depth of 24 meters, where an encounter with impenetrable material halted further progression (**Figure 2(b)**).

4. Geophysical Method: Electrical Resistivity

In this study, the electrical resistivity geophysical method was utilized as a non-invasive technique for probing subsurface conditions, based on the inherent electrical properties of ground materials. Recognized for its applications in diverse fields including environmental and engineering research, hydrogeology, mineral

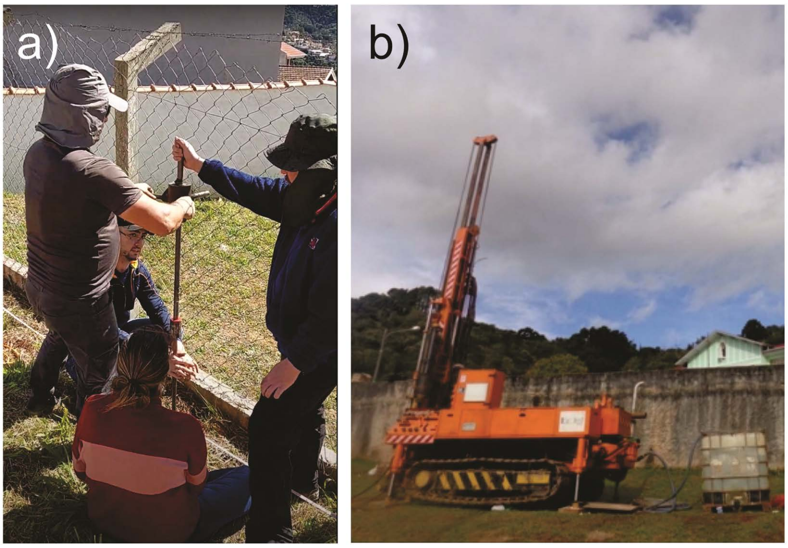

Figure 2. Photographs of the Dynamic Penetrometer Light (DPL) surveys (a) and Standard Penetration Test (SPT) surveys (b) conducted in the city of Campos do Jordão.

exploration, and archaeological investigations, this method concentrates on determining the distribution of electrical resistivity beneath the surface. The procedure entails the injection of a controlled electric current into the earth using a pair of electrodes functioning as the current source. An additional set of electrodes, termed potential electrodes, are positioned at a determined distance from the current source to gauge the voltage resulting from the injected current. By implementing varying electrode configurations and placements, a collection of data points is acquired, enabling the construction of 1D/2D/3D electrical resistivity images that depict the subsurface resistivity pattern. Specifically, within the scope of this research, two Electrical Resistivity Tomography (ERT) surveys were carried out to create a 2D profile.

The initial profile (Study Site 1) was executed utilizing a dipole-dipole array with a spacing of 0.25 m between electrodes, facilitated by a Syscal Pro resistivity meter outfitted with a 72-channel intelligent electrode system. This arrangement spanned a total length of 17.75 m (**Figure 3(a)**). The subsequent profile was conducted with the Syscal Pro resistivity meter as well, though without the incorporation of intelligent electrodes. This configuration employed a dipole-dipole array, encompassing three overlapping profiles with electrode spacings of 5 m, 10 m, and 20 m, culminating in a total electrode opening of 180 m (**Figure 3(b)**).

5. Applied Integration Methodology

The integration approach developed within this research is designed to formulate a correlation between the electrical resistivity values gathered from the geophysical survey and the N10 (DPL) and N-values (SPT). To establish this connection, a curve fitting is performed, with one axis depicting the decimal logarithm of the electrical resistivity values, and the other axis representing the corresponding N10 or N-values. The use of the decimal logarithm for electrical resistivity is a deliberate choice to temper the broad range of values inherent in this property. This decision was informed by the fact that resistivity values can span two decimal places, whereas N10 values exhibit fluctuations on a far more limited scale, varying by only a few units. The procedure initiates with the software determining the electrical resistivity along the profile at each geotechnical measurement point. This comprehensive integration strategy ensures a cohesive synthesis of data, resulting in an equation that effectively links the information extracted from the geophysical and geotechnical surveys.

For the purpose of validating the method, three DPL soundings were conducted at Study Site 1 along the geophysical profile at distances of 5 m, 10 m, and 13 m. Utilizing this dataset, a curve was fitted to facilitate the calculation of N10 values based on the resistivity of each element within the geophysical model. In order to evaluate the capability of the methodology, soundings at 5 m and 13 m were employed to derive the fitting formula, with the outcomes then compared to data gathered at a depth of 10 m. The fitting curve was obtained through two methodologies: Smooth Polynomial and Piecewise Linear, the results of which are detailed below.

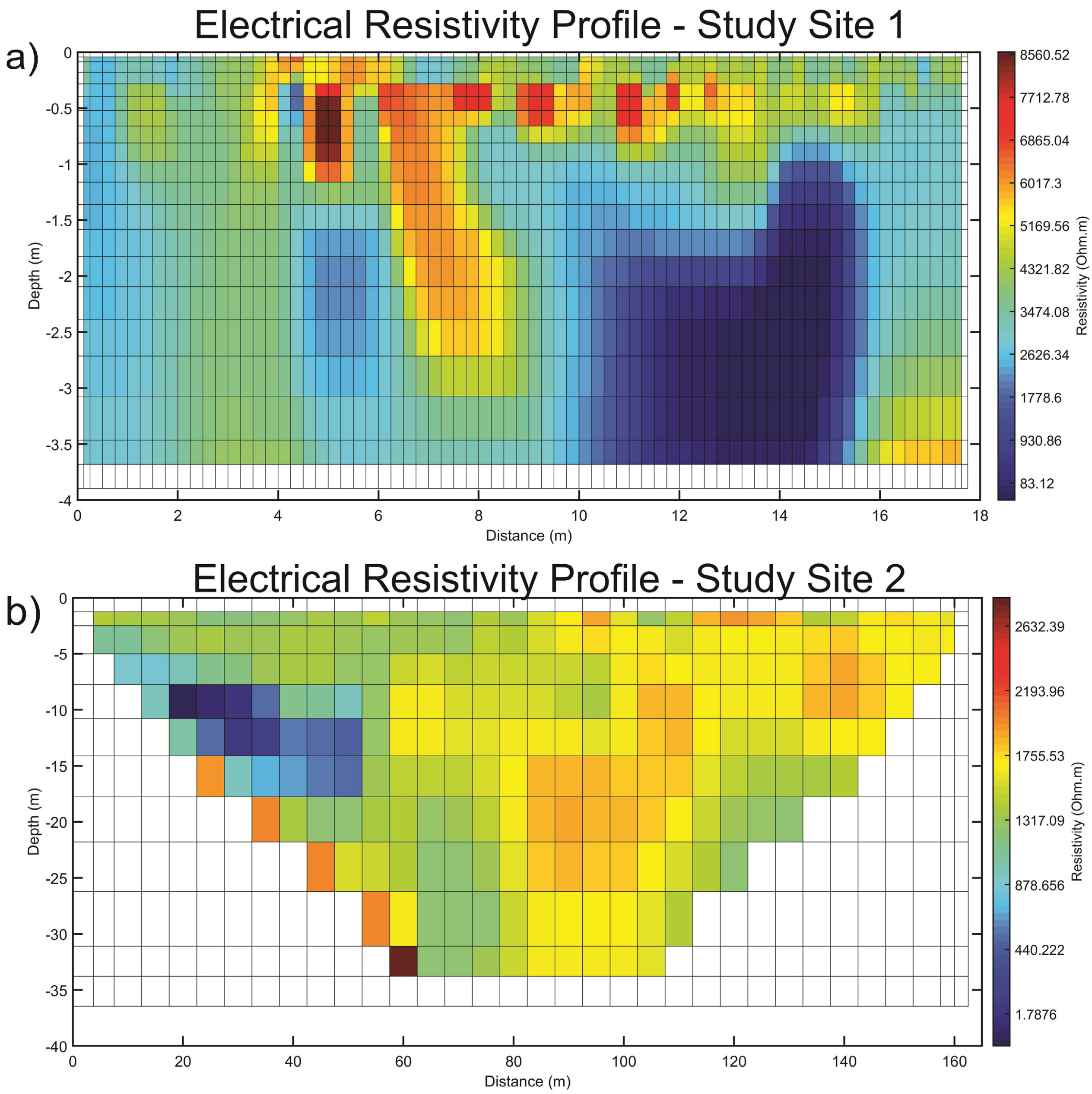

Figure 3. Acquired ERT profiles. In (a) the ERT profile at Study Site 1, and in (b) the ERT profile at Study Site 2.

5.1. Order Six Polynomial Fitting

The Smooth Polynomial fitting of order six was chosen for its superior performance among various polynomial fittings tested. Figure 4(a) illustrates the fitting process using data from the 5 m and 13 m positions, clearly indicating that the fitting was carried out efficiently, in harmony with the characteristics of the selected polynomial approach and mindful of data dispersion. Figure 4(b) displays the N10 values response for this equation (black dots), applying resistivity values from equivalent positions of the DPL sounding at the 10 m location (red dots). The graph in Figure 4(b) emphasizes the feasibility of deriving N10 values through resistivity, using a dataset that was not part of the curve fitting procedure.

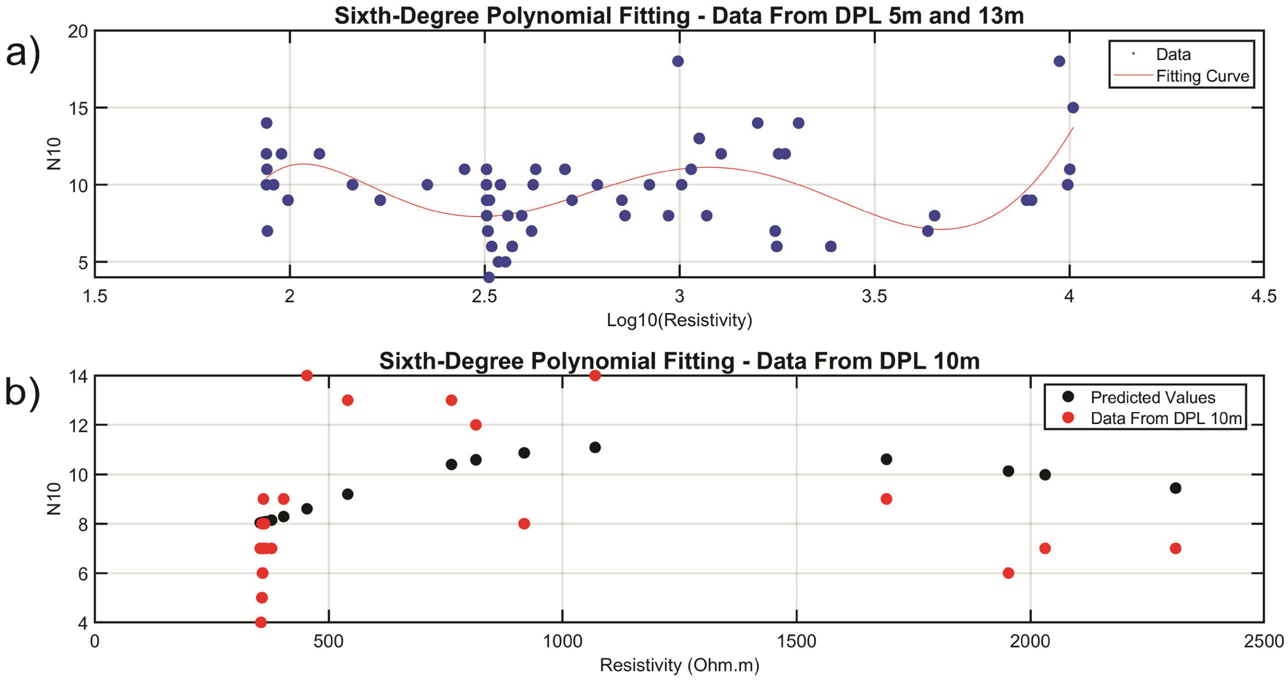

Figure 4. Sixth-Degree Polynomial fitting results. In (a) resistivity vs. N10 and the fitting curve obtained using the Sixth-Degree Polynomial and in (b) the predicted values compared with the measured data at the 10 m position (RMS = 2.32).

In this specific instance, the indirectly obtained values appear as a more uniform representation of the N10 values ascertained from the DPL sounding at 10 m, resulting in a Root Mean Square (RMS) value of 2.32.

The formula facilitates the construction of a two-dimensional model of N10 values from the geophysical profile (Figure 5). This represents a significant advancement in evaluating the mechanical strength of soil, particularly in regions susceptible to mass movements. Figure 5 demonstrates that the variations in N10 values achieved with the polynomial approach are highly consistent, reflecting the results previously detailed. Figure 6 offers a juxtaposition between the N10 values obtained directly through DPL soundings (at the 5 m, 10 m, and 13 m positions) and those calculated indirectly by employing the methodology developed in this study. The comparison clearly reveals that the calculated values closely mirror the actual data, though they present a more even pattern of fluctuation.

5.2. Piecewise Linear Fitting

Figure 7(a) illustrates the results achieved utilizing the piecewise linear fitting method. Owing to the inherent characteristics of this method, it facilitates a more accurate reflection of pronounced variations within the N10 parameter, as delineated in Figure 7(a). Figure 7(b) offers a side-by-side comparison between the actual DPL data acquired at the 10 m position (denoted by red points) and the predictions generated by the newly developed methodology (indicated by black points). It becomes clear from this comparison that the derived formula is more adept at mimicking the abrupt fluctuations observed in the N10 values, as

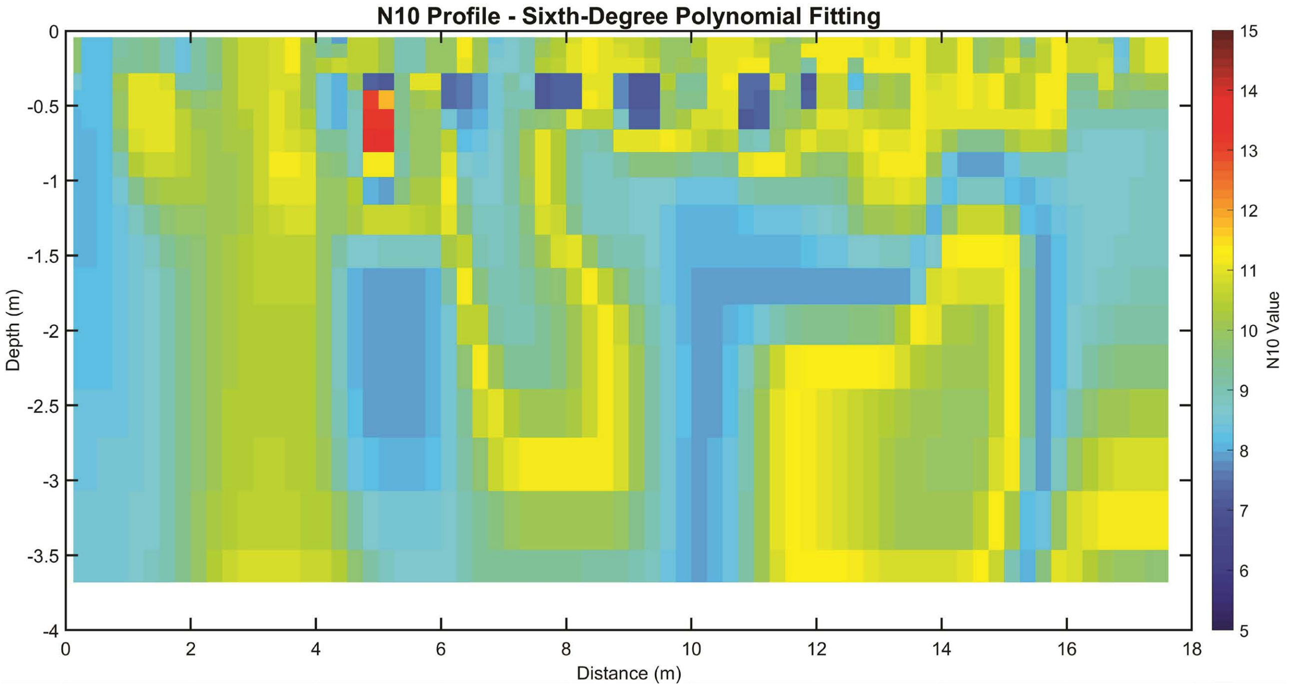

Figure 5. Two-dimensional N10 value model derived through the utilization of the Sixth-Degree Polynomial fitting formula.

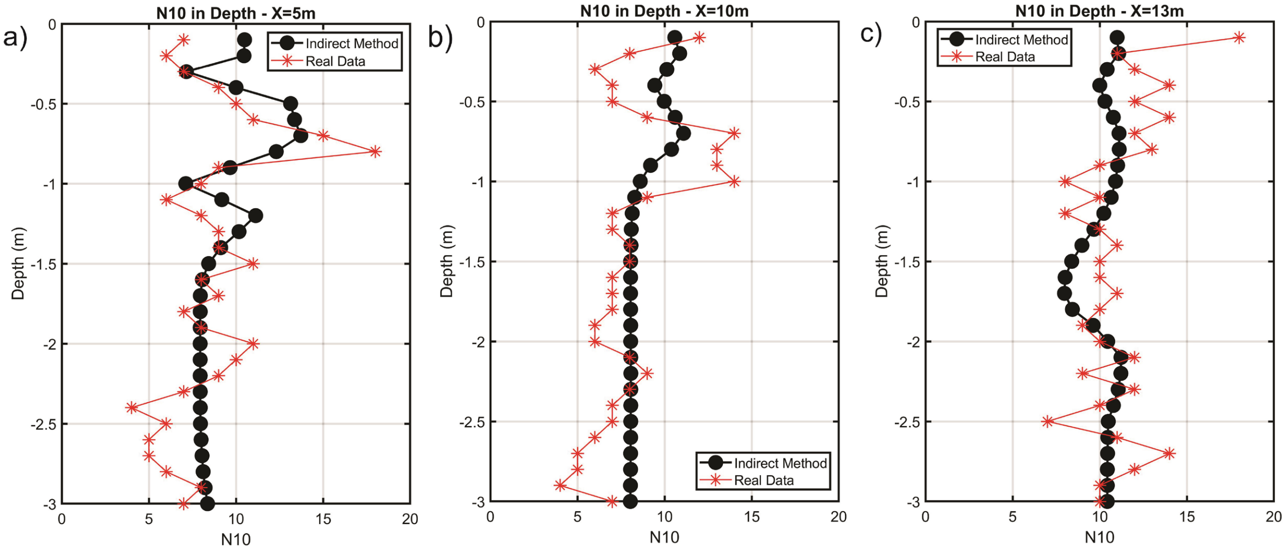

Figure 6. Comparison between the N10 values acquired through DPL soundings and those indirectly obtained using the Sixth-Degree Polynomial fitting method, at the positions of 5 m (a), 10 m (b), and 13 m (c).

opposed to the smoothed curve yielded by the prior method. In this instance, the Root Mean Square (RMS) value was 2.54, demonstrating an alignment congruent with the results produced from the preceding formulation.

Figure 8 displays the 2D model of the N10 values as they correspond to the piecewise linear fitting. In this case, the model demonstrates noticeably sharper variations in the N10 parameter compared to the previous scenario. This is more reflective of the fluctuations that were actually observed in the data gathered on site. Since the survey took place within an urban area known for its variations, a

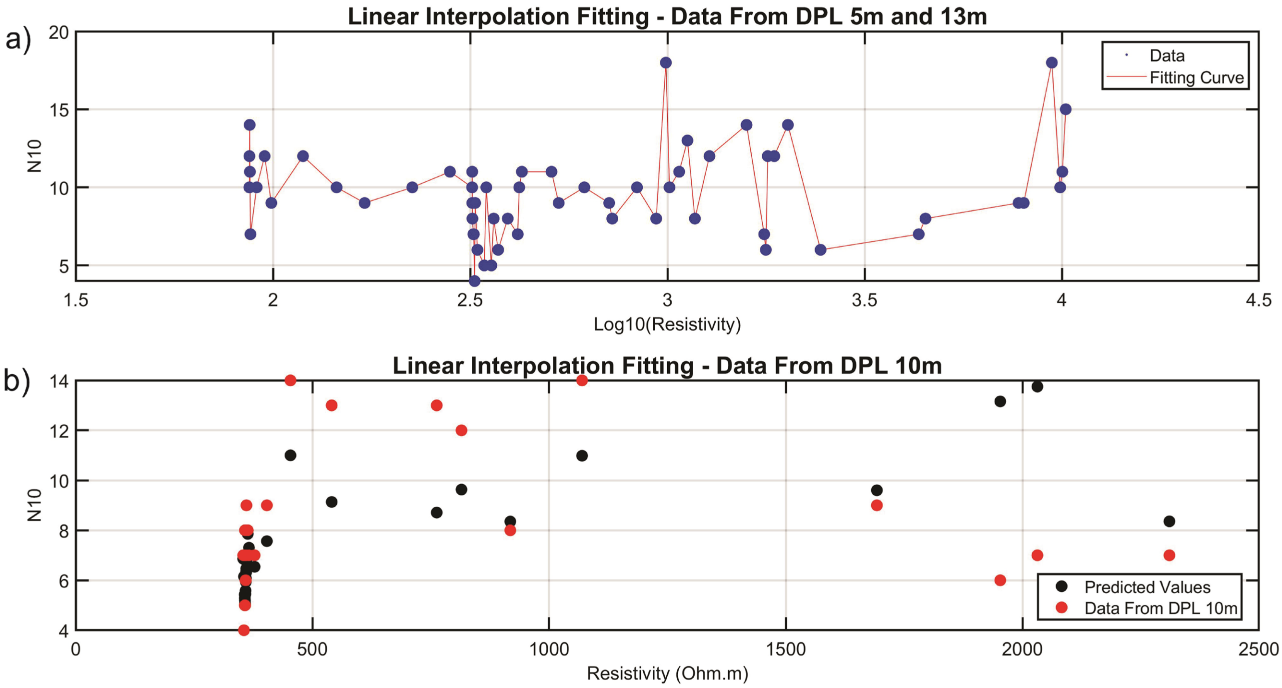

Figure 7. Piecewise Linear fitting results. In (a) resistivity vs. N10 and the fitting curve obtained using the Piecewise Linear and in (b) the predicted values compared with the measured data at the 10 m position (RMS = 2.54).

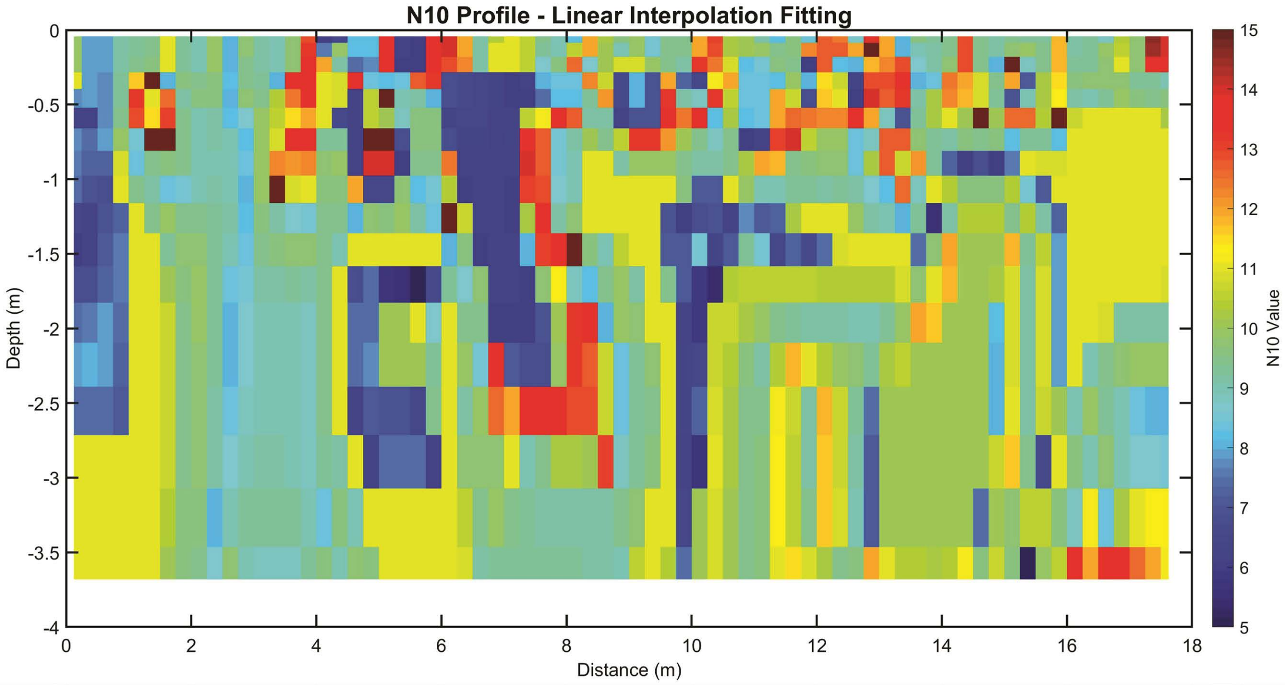

Figure 8. Two-dimensional N10 value model derived through the utilization of the Piecewise Linear fitting formula.

considerable fluctuation in N10 values at the location is expected. This depiction, therefore, provides an enhanced visualization of the site's local heterogeneities.

Figure 9 offers side-by-side comparative graphs of the DPL soundings conducted

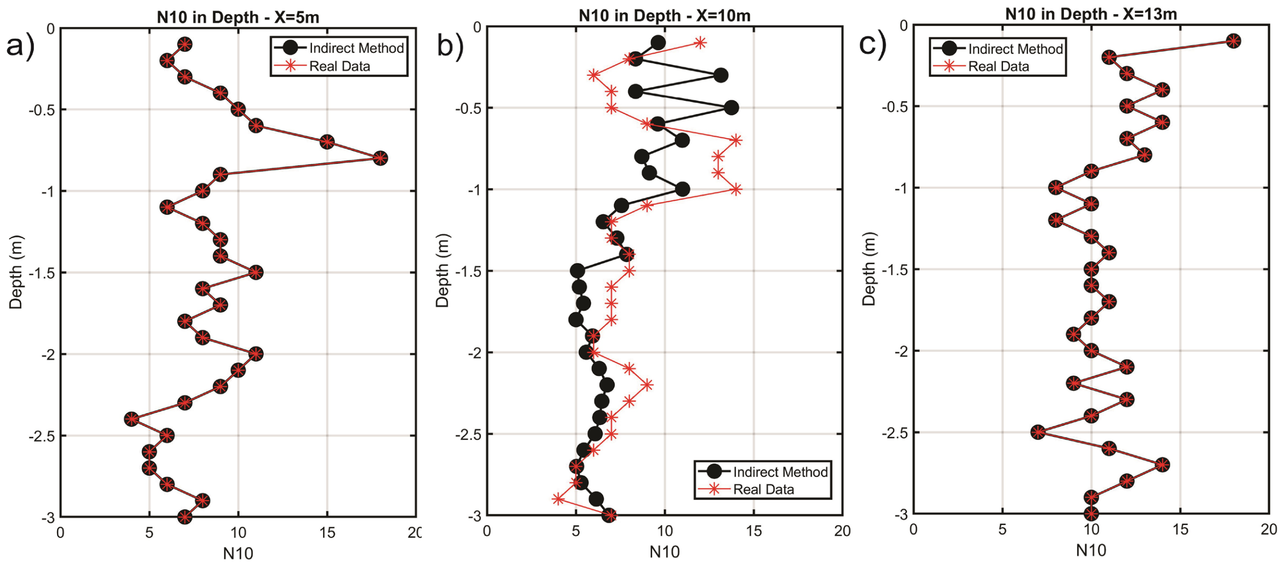

Figure 9. Comparison between the N10 values acquired through DPL soundings and those indirectly obtained using the Piecewise Linear fitting method, at the positions of 5 m (a), 10 m (b), and 13 m (c).

at the 5 m, 10 m, and 13 m positions along the profile, alongside the values predicted by the suggested methodology. Notably, in the cases of the 5 m (**Figure 9(a)**) and 13 m soundings (**Figure 9(c)**), an ideal alignment is observed. This correlation is attributed to these specific soundings being the ones utilized in the fitting algorithm. However, a true evaluation of the method's performance in this case necessitates an analysis of the 10 m sounding. Clearly, the piecewise linear fitting method excels in capturing the abrupt discontinuities encountered, thereby leading to a more accurate representation of the N10 curve's shape.

6. Standard Penetration Test (SPT)

Utilizing the methodology previously described, the goal was to ascertain the distribution of SPT N-value values from a geophysical profile performed at the location of an earlier conducted SPT sounding. As with the DPL case, resistivity values were gathered at the same locations as the SPT data, aiding the adjustment process. **Figure 10** illustrates the results of the SPT N-value values for both the Sixth-Degree Polynomial fitting method (a) and the Piecewise Linear fitting method (b), set alongside the actual data. In this situation, the Sixth-Degree Polynomial method once again succeeded in accurately tracing the data curve, albeit more smoothly, yet delivering a satisfying fit. Reflecting the nature of the technique, the Piecewise Linear approach provided an optimal alignment with the data points.

Figure 11 depicts the 2D model of the SPT N-value as determined by the Sixth-Degree Polynomial method. Echoing the DPL case, the polynomial adjustment seems to lessen the variations in SPT N-values, producing a smooth curve that represents penetration resistance. **Figure 12** introduces the two-dimensional model derived from the piecewise linear method, unveiling a more complex pattern marked by substantial fluctuations in the SPT N-value magnitudes, and exhibiting the existence of smaller-scale irregularities.

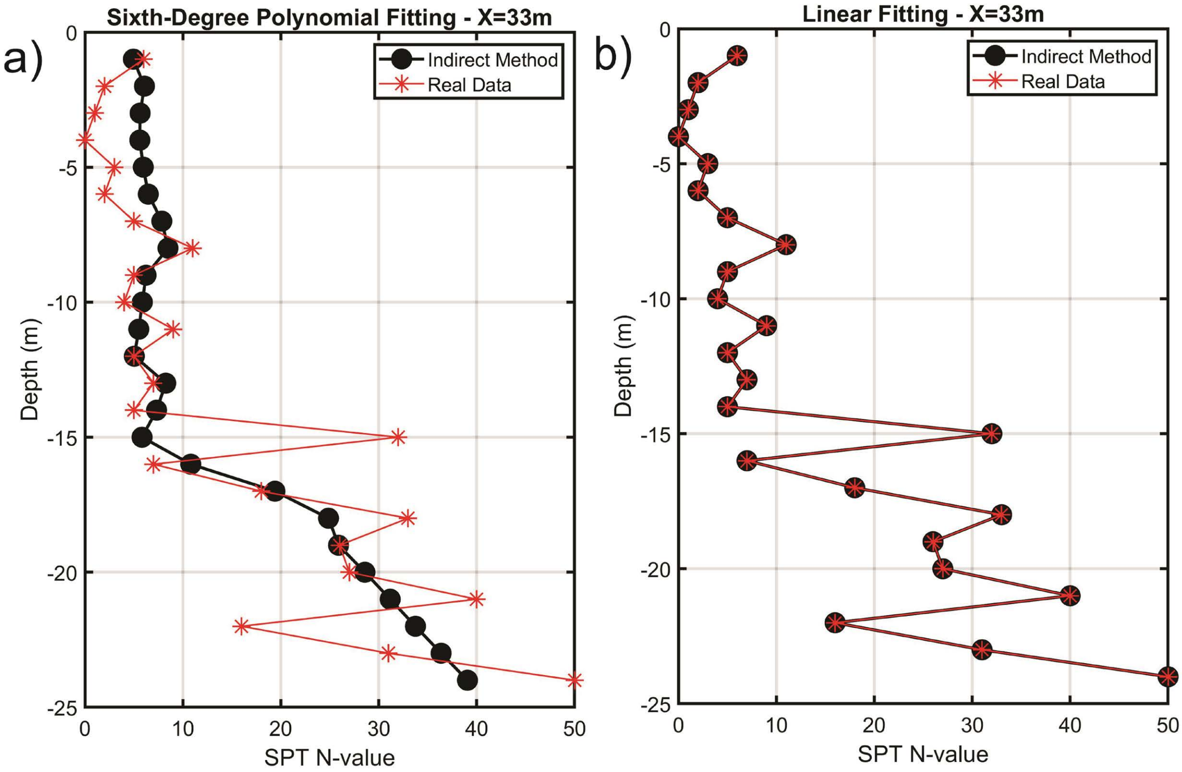

Figure 10. Comparison between the SPT N-values obtained using the Sixth-Degree Polynomial fitting method (a) and the Piecewise Linear method (b) against the actual data from the SPT sounding.

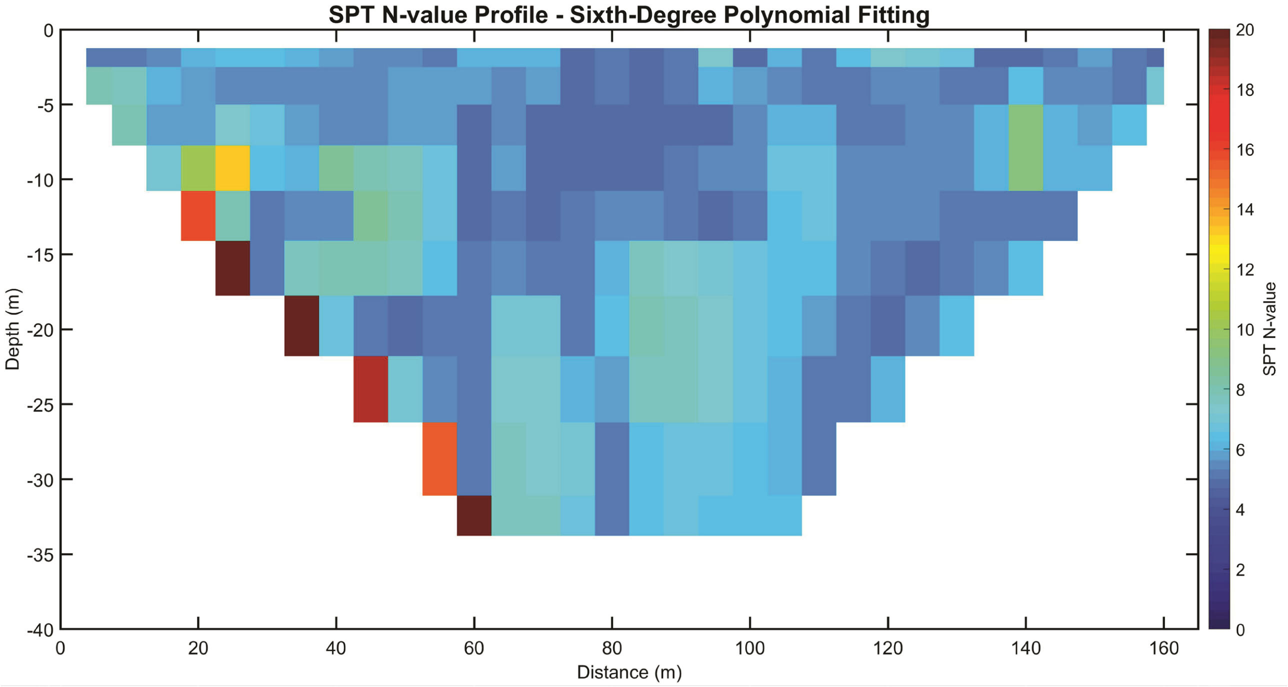

Figure 11. Two-dimensional SPT N-values model derived through the utilization of the Sixth-Degree Polynomial fitting formula.

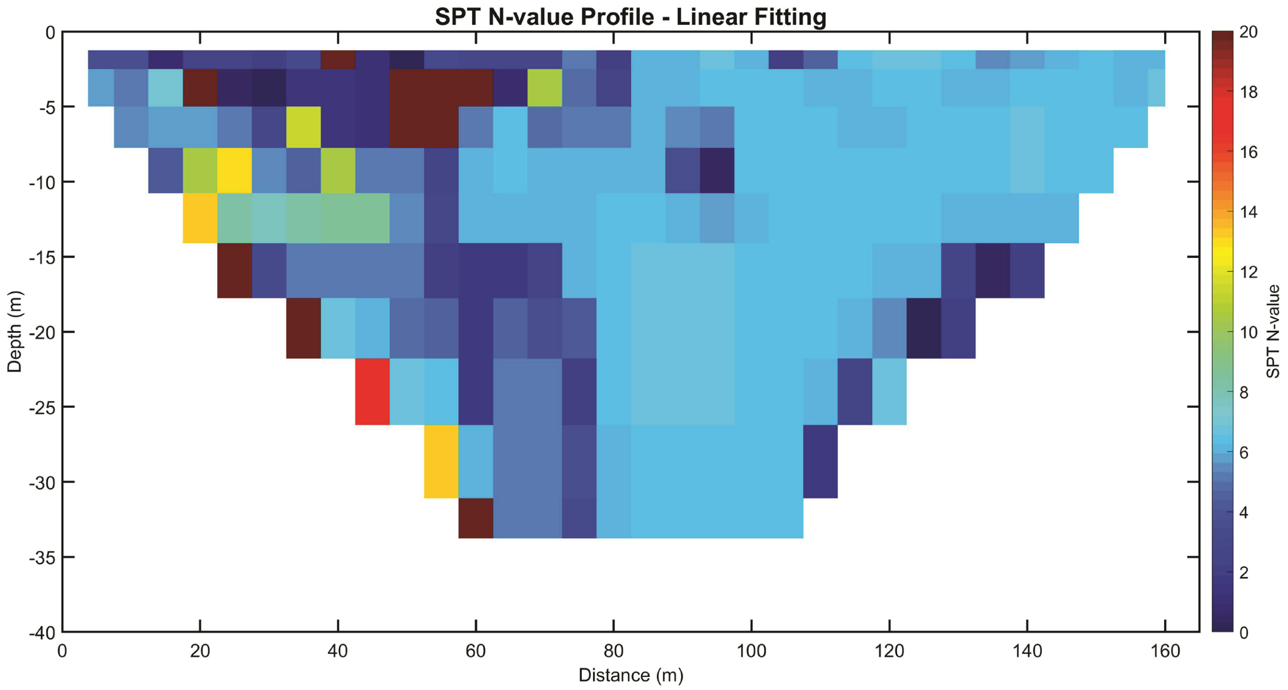

Figure 12. Two-dimensional SPT N-values model derived through the utilization of the Piecewise Linear fitting formula.

7. Discussion

The methodologies employed to derive both N10 and SPT N-value parameters have demonstrated remarkable robustness, producing results congruent with those obtained in the field, while maintaining simplicity in application. Although the polynomial fitting approach adeptly aligns with data curves, it is less adaptable to sudden variations in penetration resistance values. In contrast, within the context of the study outlined, the Piecewise Linear fitting method emerged as the more favorable technique. This method not only provides an excellent fit to the data but also adeptly captures abrupt fluctuations in both N10 and SPT N-values. While the bi-dimensional models presented have inherent limitations due to their indirect derivation, they afford an enriched understanding of the subsurface attributes by portraying them in two dimensions. This representation transcends the simplifications of a layered approximation, signifying the models' considerable potential across diverse research fields, thereby underscoring their contribution to more intricate investigations.

8. Conclusion

This paper introduces an efficient methodology for obtaining geotechnical information through the utilization of the electrical resistivity method. The extraction of geotechnical parameter distributions via geophysics furnishes a substantial edge by enabling a more nuanced discretization of the subsurface. The sophisticated visualization capabilities inherent in geophysical surveys facilitate a more meticulous and accurate portrayal of subsurface conditions. This leads to an enriched comprehension of slope behavior and significantly augments landslide risk assessments. Through the integration of geophysical and geotechnical data, the gap between isolated point information and a complete subsurface picture can be bridged, yielding essential insights for engineers and planners to make enlightened decisions and avert potential risks. Overall, the synergy between geophysical methods and conventional geotechnical investigations shows great promise in enhancing both the efficiency and precision of slope stability evaluations, thereby contributing to the overall safety and success of civil engineering endeavors.

Acknowledgements

Cassiano Bortolozo thanks to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the Postdoctoral Scholarship (grant 152269/2022-3), for the Research Fellowship Program (grant 301201/2022-6) and also for the Research Financial Support (Universal Project grant 433481/2018-8). All authors thank FINEP (Financiadora de Estudos e Projetos) for financing the REDEGEO project (Carta Convite MCTI/FINEP/FNDCT 01/2016), responsible for the PCD Geo network installation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Gonçalves, J.T.D., Botelho, M.A.B., Machado, S.L. and Netto, L. G. (2021) Correlation between Field Electrical Resistivity and Geotechnical SPT Blow Counts at Tropical Soils in Brazil. *Environmental Challenges*, **5**, Article ID: 100220. https://doi.org/10.1016/j.envc.2021.100220

[2] Bortolozo, C.A., Mendes, T.S.G., Motta, M.F.B., Andrade, M.R.M., Lavalle, L.V.A., Mendes, R.M., Simoes, S.J.C., Metodiev, D. and Renk, J. (2021a) Geofísica Aplicada em Estudos de Movimentos de Massa e Engenharia de Pequeno Porte. *Boletim SBGf*, **116**, 14-17.

[3] Khan, M.A., Basharat, M., Riaz, M.T., Sarfraz, Y., Farooq, M., Khan, A.Y., Pham, Q.B., Ahmed, K.S. and Shahzad, A. (2021) An Integrated Geotechnical and Geophysical Investigation of a Catastrophic Landslide in the Northeast Himalayas of Pakistan. *Geological Journal*, **56**, 4760-4778. https://doi.org/10.1002/gj.4209

[4] Passierb, B., Grodecki, M. and Gwózdz, R. (2019) Geophysical and Geotechnical Approach to a Landslide Stability Assessment: A Case Study. *Acta Geophysica*, **67**, 1823-1834. https://doi.org/10.1007/s11600-019-00338-7

[5] Bortolozo, C.A., Motta, M.F.B., Andrade, M.R.M., Lavalle, L.V.A., Mendes, R.M., Simões, S.J.C., Mendes, T.S.G. and Pampuch, L.A. (2019a) Combined Analysis of Electrical and Electromagnetic Methods with Geotechnical Soundings and Soil Characterization as Applied to A Landslide Study in Campos do Jordão City, Brazil. *Journal of Applied Geophysics*, **161**, 1-14. https://doi.org/10.1016/j.jappgeo.2018.11.017

[6] Mezerreg, N.E.H., Kessasra, F., Bouftouha, Y., Bouabdallah, H., Bollot, N., Baghdad, A. and Bougdal, R. (2019). Integrated Geotechnical and Geophysical Investigations

in a Landslide Site at Jijel, *Algeria*. *Journal of African Earth Sciences*, **160**, Article ID: 103633. https://doi.org/10.1016/j.jafrearsci.2019.103633

[7] Bortolozo, C.A., Lavalle, L.V.A., Andrade, M.R.M., Motta, M.F.B., Mendes, R.M., Metodiev, D., Pacheco, T.C.K.F., Guedes, M.R.G. and Porsani, J.L. (2018) Geophysical Methods to Characterize a Mass Movement Event in Tropical Soils in Campos do Jordão City, Brazil. *First Break*, **36**, 71-73. https://doi.org/10.3997/1365-2397.n0115

[8] Rezaei, S., Shooshpasha, I. and Rezaei, H. (2018) Empirical Correlation between Geotechnical and Geophysical Parameters in a Landslide Zone (Case Study: Naigeschal Landslide). *Earth Sciences Research Journal*, **22**, 195-204. https://doi.org/10.15446/esrj.v22n3.69491

[9] Lavalle, L.V.A., Bortolozo, C.A., Pacheco, T.C.K.F., Andrade, M.R.M., Motta, M.F.B., Mendes, R.M., Metodiev, D., Guedes, M.R.G. and Porsani, J.L. (2018) Evaluation Methodology for Obtaining Geotechnical Parameters Using Electrical Resistivity. *First Break*, **36**, 55-58. https://doi.org/10.3997/1365-2397.n0112

[10] Devi, A., Israil, M., Anbalagan, R. and Gupta, P.K. (2017) Subsurface Soil Characterization Using Geoelectrical and Geotechnical Investigation at Bridge Site in Uttarakhand Himalayan Region. *Journal of Applied Geophysics*, **144**, 78-85. https://doi.org/10.1016/j.jappgeo.2017.07.005

[11] Bortolozo, C.A., Andrade, M.R.M., Mendes, R.M., Mendes, T.S.G., Simões, S.J.C. and Renk, J. (2021) Seleciona_Dados_PCD. Registro de Software—Número do Pedido: BR 51 2021 002219-0. *Revista da Propriedade Industrial*, **2647**, 6.

[12] Bortolozo, C.A., Andrade, M.R.M., Mendes, R.M., Mendes, T.S.G., Simões, S.J.C. and Renk, J. (2021) Tempo_de_Retorno_Automatico. Registro de Software—Número do Pedido: BR 51 2021 002220-3. *Revista da Propriedade Industrial*, **2647**, 6.

[13] Bortolozo, C.A., Andrade, M.R.M., Mendes, R.M., Mendes, T.S.G., Simões, S.J.C. and Renk, J. (2021) Tempo_de_Retorno_Manual. Registro de Software—Número do Pedido: BR 51 2021 002221-1. *Revista da Propriedade Industrial*, **2647**, 6.

[14] Bortolozo, C.A., Andrade, M.R.M., Mendes, R.M., Simões, S.J.C. and Mendes, T.S.G. (2020) Analise_PCD_Cemaden. Registro de Software—Número do Pedido: BR 51 2020 002865-9. *Revista da Propriedade Industrial*, **2607**, 16.

[15] Bortolozo, C.A., Simões, S.J.C., Andrade, M.R.M., Mendes, R.M., Lavalle, L.V.A., Motta, M.F.B., Metodiev, D. and Mendes, T.S.G. (2019b) Guara. *Revista da Propriedade Industrial*, **7**, 15.

[16] Bortolozo, C.A., Andrade, M.R.M., Mendes, R.M., Lavalle, L.V.A., Motta, M.F.B. and Simões, S.J.C. (2017) CALAMAR. Registro de Software—Número do Pedido: BR 51 2017 001154-0. *Revista da Propriedade Industrial*, **2437**, 75-76.

[17] Lavalle, L.V.A., Bortolozo, C.A., Moraes, M.A.E., Andrade, M.R.M., Motta, M.F.B., Carvalho, P.E.P. and Mendes, R.M. (2017) SOLAM. Registro de Software—Número do Pedido: BR 51 2017 001354-3. *Revista da Propriedade Industrial*, **2442**, 18-18.

[18] Nilsson, T.U. (2004) Comparações entre DPL Nilsson e SPT. *Simpósio de Prática de Engenharia Geotécnica da Região Sul* (*GeoSul* 2004), Curitiba, 20-22 May 2004.

[19] Nilsson, T.U. (2008) Parameter Approach from DPL Test. *International Conference on Site Characterization*, Taipei, 1-4 April 2008.

[20] Nilsson, T.U. (2004) O penetrômetro portátil DPL Nilsson. *Seminário de Engenharia de Fundações Especiais e Geotecnia*, São Paulo, 22-24 November 2004.

[21] ASTM D1586-11 (2022) Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils. ASTM International, West Conshokocken.