Integration of Direct and Indirect Techniques to Optimize Subsurface Exploration

Wijesinghe LV, Ineshka WSS, Sutharsini S, *Jayawardena CL and Samaradivakara GVI

Department of Earth Resources Engineering, University of Moratuwa
*Corresponding author – chulanthaj@uom.lk

Abstract: Subsurface exploration is one of the major activities conducted to extract information for Geotechnical applications. Borehole construction is the most common direct exploration technique which provides exact information on a particular location whereas, Electrical Resistivity Method is one of the commonly practiced indirect exploration techniques. Since the exploration costs are relatively high, minimizing the cost while obtaining adequate information is of everyone's interest. For larger constructions with deep foundation requirements, determining the overburden thickness (bedrock level) and water table is a mandatory requirement. Hence, the use of a proper combination of direct and indirect subsurface exploration methods could result a considerable cost reduction and time saving. This study was conducted to find an optimum integration of resistivity method and borehole construction for selected subsurface exploration activities currently in progress. Accordingly, resistivity surveys were conducted at sites proposed for a twelve storied residential tower at Malabe and Matara – Kataragama Railway Extension Project, near piers for new railway track. Apparent resistivity data were gathered using ABEM – Terrameter SAS 1000 instrument, were interpretated using "IP 2 Win" software. The results were validated using the borehole information. The resistivity survey information revealed a close relationship with the borehole data and resides within the statistically acceptable range. Hence, an optimum combination of resistivity surveying and borehole construction can be proposed, for cost controlling at large-scale subsurface explorations.

Keywords: Resistivity Survey, Overburden Thickness, Groundwater Table

1. Introduction

The objective of a preliminary subsurface exploration is to gather information on the overburden thickness (bedrock level) and depth to groundwater table. The purpose of land use and required paramteres for the proposed design in general, determines the level of detail investigations required. The direct exploration techniques disturb the subsurface and reveal exact information consuming a considerable cost and time [1]. Indirect techniques measure at or near earth properties without disturbance, by using the internal physical properties of the subsurface [2 and 3]. Electrical Resistivity, Ground Penetrating Radar (GPR), Seismic, Magnetic and Gravity are some popular indirect exploration methods. Irrespective to the rapid surveying ability, the indirect methods require validation of the interpretations [4]. However, the main advantages of indirect techniques over direct methods are; cost effectiveness and less time consumption [1].

In general, the investment for the subsurface exploration increases proportionally with the scale of the project. Hence, the main intention of large scale projects are to minimize the cost of exploration while gathering adequate subsurface information with a considerable accuracy. Cost controlling while maintaining the required standards is a tedious task. Only a correct combination of direct and indirect exploration techniques may provide the optimum results [2].

This study evaluates the accuracy of the resistivity surveying to determine the overburden thickness at selected sites and provides an empirical equation to improve the thickness calculations. It also gives directions to optimise the use of direct and indirect exploration methods at the above sites.

2. Methodology

2.1 Selection of sites

The site selection was mainly concerned on the scale of the ongoing project, availability of the subsurface information and accessibility. A site intended to build a twelve storied residential tower at Malabe (Orchid by Nivasie) was one location of interest, where five boreholes had been advanced on site; with four at the corners and one at the middle. Three resistivity surveys were conducted in differently directed traverses (Figure 1).

Figure 1: Orchid by Nivasie, Malabe [Not to scale]

Nilawala Bridge No. 2, of Matara-Kataragama Railway Extension project, was also a location of interest. The boreholes had been advanced at 25 m intervals, and at each pier of the continuation where a total of six resistivity surveys were conducted parallel to the new railway track (Figure 2).

Figure 2: Nilawala bridge No.2 [Not to scale]

Resistivity surveys were also conducted in three locations at the playground of University of Moratuwa in order to determine a suitable location for an experimental tube-well (Figure 3).

Figure 3: Playground, University of Moratuwa [Not to scale]

2.2 Resistivity surveying

The survey lines were selected mainly considering the availability of subsurface information, space for resistivity traverse and flatness of the terrain. After determining the base point, the GPS coordinates were recorded. A peg was placed at the base point and Terrameter SAS 1000 – ABEM instrument was located nearby. Two measuring tapes were layed to opposite directions from the base point along the selected survey line. Current and potential electrodes were then penetrated to the ground at required spacing and wire connections were established to the relevant terminals in the instrument. An external DC (12 V) power source was used as the power source.

The instrument was operated in resistivity mode and the apparent resistivity measurements were recorded similar to the previously followed work [4 and 5]. Vertical Electrical Soundings (VES) in line with Schlumberger configuration was carried out at the selected sites.

2.3 Interpretations

"IP-2-Win" software was used to perform (1-D) interpretatios for the resistivity survey data. Half of the current electrode spacing values with the corresponding apparent resistivity values were fed as the input to the software. Error correction was implemented on the values with an unrealistic deviation. The output of half of the electrode spacing vs. apparent resistivity graph with an error less than 5% was obtained. This was similar to the previously followed interpretations [4 and 6].

3. Results

3.1 Orchid by Nivasie, Project site, Malabe

Summary of the actual and interpreted overburden thickness results relevant to the conducted resistivity surveys at Malabe site are given in Table 1.

Table 1: Results of surveys at Malabe site

Survey Line No.	Actual Overburden Thickness (m)	Interpreted Overburden Thickness (m)
4.1	9.00	8.774
4.2	9.00	7.710
4.3	9.00	8.799

3.2 Nilwala bridge No.2, Matara-Kataragama railway extension project

Summary of the actual and interpreted overburden thickness results relevant to the conducted resistivity surveys at Matara – Kataragama railway extension project are shown in Table 2.

Table 2: Results of Matara-Kataragama railway extension project

Survey Line No.	Actual Overburden Thickness (m)	Interpreted Overburden Thickness (m)
5.1	19.05	15.60
5.2	19.50	15.71
5.3	21.04	18.84
5.4	18.08	15.30
5.5	17.52	18.46
5.6	7.33	8.82

3.3 Ground, University of Moratuwa (UoM)

It was difficult to determine the groundwater level and overburden thickness for locations 1 and 3 mostly due to the site obstacles which limited the current electrode span.

Table 3: Results of location 2, ground, UoM

Survey Line No.	Interpreted Overburden Thickness (m)	Interpreted Depth to Groundwater Table(m)
2.1	11.4	5.61
2.2	11.7	6.20
2.3	12.3	5.61
2.4	15.0	5.86

Table 4: Results of location 3, ground, UoM

Survey Line No.	Interpreted Depth to Groundwater Table(m)
3.1	6.58
3.2	5.87
3.3	-

4. Discussion

4.1 Statistical analysis of data

Overburden estimation through the resistivity data, with respect to borehole data has an equal variance (F-test value greater than 0.05) which reflects the characteristics of similar data sets. The T-Test value reveals that the estimated values differ only by 11.4% from the actual.

Table 5: Statistical analysis of results

Survey Line No.	Actual Overburden Thickness (m)	Interpreted Overburden Thickness (m)
5.1	19.05	15.60
5.2	19.50	15.71
5.3	21.04	18.84
5.4	18.08	15.30
5.5	17.52	18.46
5.6	7.33	8.82
4.1, 4.2, 4.3	9.00	8.43
F-Test		**0.55**
T-Test		**0.11**
Correlation Coefficient		**0.93**

The correlation coefficient (0.93) is also within the range of 0.8-1, reflecting a strong relationship between the estimated overburden thickness and actual value.

The interpreted overburden thickness through resisitivity surveying was plotted against the actual overburden thickness referred from borehole measurements and the relationship derived is given in Figure 4 and equation 1.

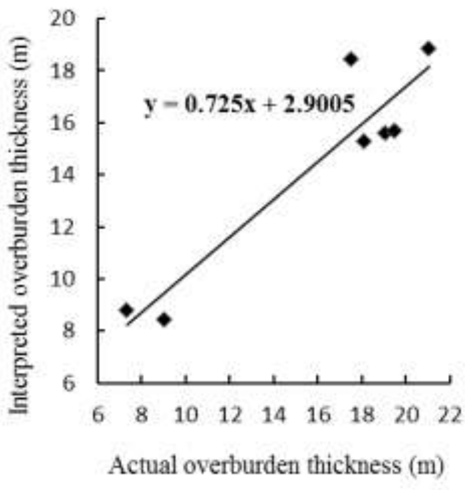

Figure 4: Mathematical relationship between interpreted and actual data

$y = 0.725x + 2.9005$ .... (1)

where; y is the interpreted overburden thickness by means of resistivity survey data and x is the actual overburden thickness referred from borehole data.

4.2 Optimization of subsurface exploration

Overburden thickness exploration activities for Matara-Kataragama Railway Extension Project may be optimized using one of the three options proposed by the study. The results are summarized in Table 6.

Option 1 – Advancing boreholes at 50 m spacing and conducting resistivity surveys in between

Option 2 – Advancing boreholes at 75 m spacing and conducting resistivity surveys with 25 m spacing of centre points

Option 3 – Advancing boreholes at 100 m spacing and conducting resistivity surveys with 25 m spacing of centre points

Table 6: Statistical results for the three options of overburden thickness estimation

Survey Line No.	Option 1	Option 2	Option 3
5.1	19.05	19.05	19.05
5.2	15.71	15.71	15.71
5.3	21.04	18.84	18.84
5.4	15.30	18.08	15.30
5.5	17.52	18.46	17.52
Correlation Coefficient	**0.916**	**0.921**	**0.926**

The obtained correlation coefficients for all the options are within the acceptable range (0.8 - 1). Hence, the relationship between each option with the actual overburden thickness is confirmed. Accordingly, the option 3 gives the optimum combination of direct and indirect methods. It suggests the minimum amount of boreholes with each having a 100 m spacing and resistivity surveying at a 25 m spacing is sufficient to interpret the overburden thickness for this investigation.

To optimize the subsurface exploration at Malabe site, it can be suggested to replace the middle borehole by two diagonal resistivity survey lines connecting the corner boreholes at each end.

4.3 Improving the accuracy of interpretations

The equation (1) can be used to improve the accuracy of the interpreted overburden thickness. Table 7 shows statistical results when the modified values of overburden thickness is used.

The correlation coefficients of the three options have been increased in comparision to the values given in Table 6. It indicates a better relationship among the actual overburden thickness and modified estimation of overburden thickness with the help of equation (1).

Table 7: The three options with modified overburden thickness values in use

Survey Line No.	Option 1	Option 2	Option 3
5.1	19.05	19.05	19.05
5.2	15.71	15.71	15.71
5.3	21.04	18.84	18.84
5.4	15.30	18.08	15.30
5.5	17.52	18.46	17.52
Correlation Coefficient	**0.986**	**0.928**	**0.951**

4.4 Limitations and influential factors

- The study does not address on the cost factor for both direct and indirect exploration activities. Hence, analysis lacks the economical aspects of optimization. However, deriving an emphirical equation to improve on the depth estimations through resistivity surveying facilitates the optimum use of the indirect method.
- Descrepencies between the actual and estimated overburden thicknesses for the railway project is inevitable as most of the boreholes were constructed prior to the pilot road construction, on which the resistivity survey traverses took place. The lateral variations in the overburden thickness could also influence the interpretations, as the resisitivity survey lines and borehole locations do not overlap accurately.
- It was difficult to make an estimation on the overburden thickness or the groundwater level at two locations of the university ground, possibly due to the extensive fill that exist. However, the location 2 provided sufficient information with a groundwater table which is approximately at

5.82 m depth, and an average overburden thickness of 12.6 m. Therefore, location 2 was proposed as a suitable site for the experimental borehole construction.

- The Electrical Resistivity Method provides better subsurface information with a high accuracy, under ideal conditions. However, accuracy of the measurements may vary due to the reasons such as; lateral variations within the current electrodes, heterogeneity in subsurface material, complex geology, existence of natural currents and potentials [7], extreme dry ground conditions, heavy sunlight and inability of obtaining a perfect flat terrain for the survey line.
- The instrument was giving erroneous readings when occupied under strong direct sunlight. Providing sufficient shelter to the instrument is a must under such environments [8]. Use of salt-water to improve the electrode ground contact may necessary on the dry surfaces where the readings were erroneous.
- False resistivity readings may produced under high tension lines, buried or surface present steel objects, heavy concrete structures and deep foundations like piles in near distance to the survey line.

5. Conclusions

The study provides a guideline for the optimum use of direct and indirect subsurface exploration techniques under local conditions to achieve sufficient information on the overburden thickness. Further, it derives an empirical equation that improves the accuracy of overburden thickness calculations, obtained through the resistivity data.

Acknowledgement

The authors are greatful for those who facilitated the field work as well as, provided constructive criticism to fine tune the study. Assistance from Mr. AMR Bandara, (Manager Investigations, Water Supply & Drainage Board), Mr. L Dhanushka (Geotechnical Engineer, Matara-Kataragama Railway Extension Project) and Engineering and Laboratory Services (Pvt) Ltd, specially acknowledged.

References

[1] Biscan, M., Bolfan, L., Matkovic, I. and Vajdic, M. (2014) Optimization of geotechnical investigation works during the reconstruction of the transition zones on the old railway lines. Paper presented at the 3rd International Conference on Road and Rail Infrastructure, Split, Croatia. 28-30 April.

[2] Kearey, P., Brooks, M. and Hill, I. (2002) An introduction to geophysical exploration. 3rd ed. Victoria: Blackwell Science, pp. 183-207

[3] Telford, W. M., Geldart, L. P. and Sheriff, R. E. (1990) Applied geophysics. 2nd ed. Cambridge, England: Cambridge University Press England: Cambridge University Press

[4] Nupearachchi, C. N., Prematilaka, K. M., Attanayake, A. N. B. and Fernando G. W. A. R. (2010) Subsurface geological and hydrogeological conditions of the Matale district, Sri Lanka: inferred

from vertical electrical sounding curves. OUSL Journal. 6: 91-102

[5] Senerath, H. G., Samaradivakara, G. V. I. and Ekanayake, E. M. K. B. (2000) Resistivity soundings for groundwater exploration-a case study. Engineer. 33(2): 20-26

[6] Kurniawan, A. (2009) Basic IP2 Win tutorial. Hydrogeology World

[7] Cardimona, S. n.d. Electrical resistivity techniques for subsurface investigations, viewed 16 October 2015, http://www.dot.ca.gov/hq/esc/geotech/geo_support/geophysics_geology/documents/geophysics_2002/061cardimona_resistivity_overview.pdf

[8] Instruction Manual: ABEM Terrameter SAS 1000/4000. (2008) Sweden: ABEM Instrument AB