Determination of the Unknown Length of a Pile Partially Embedded in Rock using Induction Logging Testing in Brazil

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ABSTRACT

The results of an electromagnetic test of recent application in Brazil, called induction-logging (IL) test, intended to determine the depth of a foundation element, will be presented in this article. The application has been conducted on a 250-mm diameter root-pile belonging to the foundations of a telecommunications tower located in São Paulo, Brazil. The estimated depth of the foundation element was obtained by the analysis of the results from the IL test, and was evaluated as ranging from 7.0 to 7.5 m, which was later verified to be in agreement with the design drawings for the pile. With respect to the induction logging test, more promising results might have been achieved had the borehole been located closer to the foundation element.

KEYWORDS: root-pile, foundation, Induction-logging (IL) test, telecommunications tower.

INTRODUCTION

Determining the length and geometry of the foundation elements for telecommunications towers without documentation is becoming an increasingly important task for the nondestructive testing community. For most of these foundations, the lack of any information is not a major concern if the structure has been performing adequately for a period of years. However, a variety of situations can arise in which suddenly the task of determining the foundation depth and geometry becomes of prime importance. The most common situation, which arises, is a planned change in the loading applied to the foundation element. For antenna towers, this situation occurs when new or heavier antenna elements are added to the tower. Ignorance of the foundation depths is a frequent problem that arises from the non-availability of blueprints, the absence of a foundation project, or from existing but unreliable information. This paper presents the results of an application of induction logging (IL) test to determine the depth of a foundation element of a telecommunications tower located in São Paulo, Brazil. The induction logging test, which requires the presence of a borehole positioned very close to the foundation element to be investigated, is capable of providing more accurate and reliable results than simpler geophysical methods restricted to the ground surface, which are generally unsatisfactory for this purpose. With respect to the induction logging test, more promising results might have been achieved had the borehole been located closer to the foundation element.

LITERATURE REVIEW

Deep foundation structures generally contain steel reinforcement bars or at least imbedded steel wires for pre-tensioning, and occasionally the outer case of the pile is actually made of steel. These steel rebars, wires and casings are generally more conductive of electric current than the surrounding soil in which the foundation is embedded. If the induced magnetic field measured in a borehole located in the vicinity of the foundation element can be assumed to be induced by the steel pertaining to the foundation element, an estimate of the depth to the foundation element can be obtained. Figure 1 illustrates the basic concepts and the measuring system.

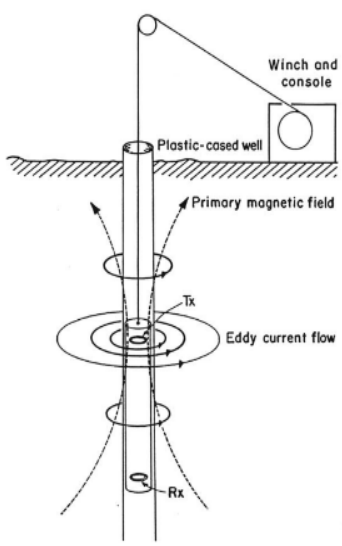


Figure 1: Illustration of the working principle of the Induction Logging Test (McNeill, 1990).

Tests with electromagnetic induction measurements are widely used to map groundwater contamination plumes, for groundwater exploration, and for general geological mapping. Surface inductive surveys for measuring layer electric conductivities are used to detect conductive features such as buried metal objects, ore bodies, and fluid-filled fractures, and to map conductive plumes of inorganic chemicals, such as landfill leachate, or saltwater intrusion (McNeill, 1980; Mondelli, 2008).

Induction Logging (IL) for measuring conductivity of the formation around the borehole, can be used to identify the placement of screening in ground-water monitoring wells, monitor contamination levels outside of cased wells, and detect or monitor contamination plumes in the vadoze zone. The use of two or more receiver coils allows the investigation at different radii from the well center.

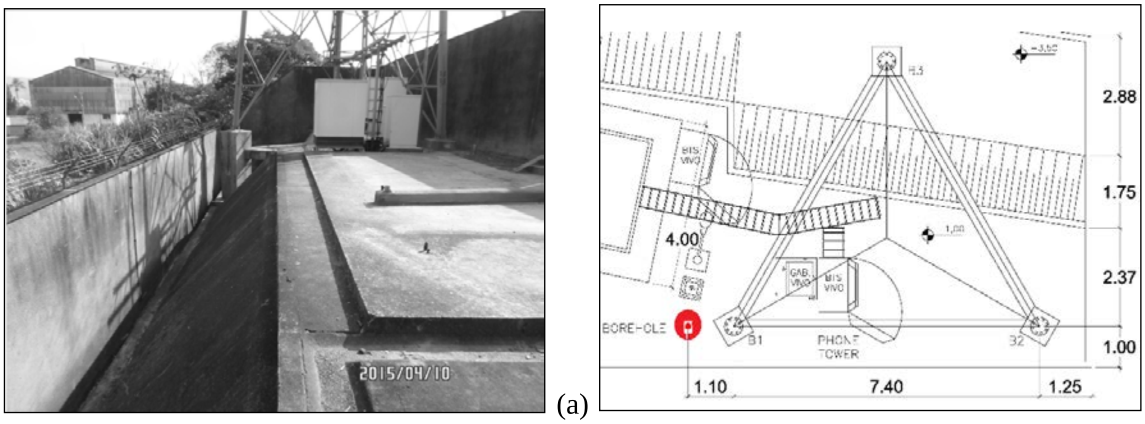
When interpreting the results, for some probes, a linear relationship between the electric potential and the conductivity of the medium is not valid when the media present high electric resistivity, i.e., a resistivity greater than 100 ohm.m (Scott et al., 1986), and non-linearity is observed.

Besides the electric conductivity, the induction probe is equipped with sensors that can record the logging of natural gamma ray in the surrounding formation, i.e., the concentration in counts per second (CPS) of natural gamma ray emitting radioisotopes from the uranium (U) and thorium (Th) decay series and potassium (K)-40. These radioisotopes tend to be more abundant in clays as a result of potassium-rich feldspar and mica decomposition, and of uranium and thorium concentrations in the clay due to adsorption and ion exchange. Gamma-emitting radioisotopes of anthropogenic origin cannot be differentiated from naturally occurring isotopes in natural-gamma ray logging. Variations in the gamma log are used to indicate lithologic changes in the formation surrounding a borehole, i.e., the presence of clayey materials (Keys, 1997, Luthi, 2001).

More innovative than the aforementioned applications, is the use of the IL test to determine the depth of a steel or continuously-reinforced concrete foundation element based on the contrast between the electrical conductivity recorded along the element length, and that occurring below the tip of the foundation element, i.e., representative of the geologic material.

PROJECT SCOPE

The IL test was performed at a telecommunication tower located in Santana de Parnaíba, metropolitan area of São Paulo, Brazil (Figure 2). Figure 2a shows a lateral view of the three-legged tower structure, and Figure 2b depicts a plan-view schematic of the location of the tower in reference to the site.



(a) (b)

Figure 2: Santana de Parnaíba site: (a) lateral view of the telecommunication tower at the testing site, and (b) plan-view location schematic.

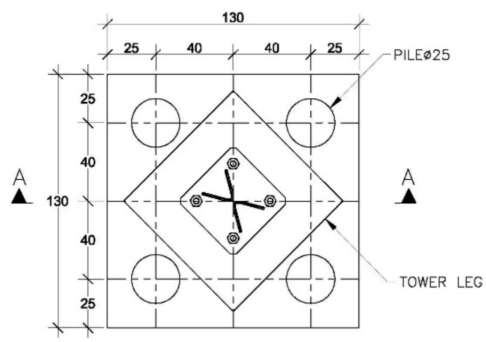
A vertical borehole to be used for the IL tests was drilled at the site at the position marked in Figure 2b, 1.1 m apart from the foundation block. The borehole was drilled to a depth of 12.5 m, exceeding by 3 to 5 m the expected foundation depth. The borehole was encased with an 85-mm internal-diameter PVC tube, closed at the bottom, and the annular space was totally filled with cement grout.

The stratigraphic profile at the location of the borehole is depicted in Figure 3, and includes a superficial 2.0-m thick fill layer consisting of a brown sandy silt followed by a layer (2.0 to 12.5 m) of an altered meta-sandstone belonging to the São Roque Group, light brown in color, friable (C4), very altered (A4) and fragmented (F5). The local water table was not encountered above the depth of 12.5 m.

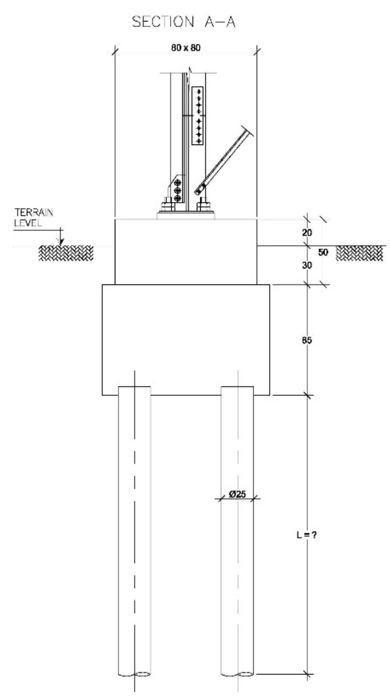
Site: Santana de Parnaíba SRB001VV **Date**: 06-August-14				**SM:** 02	**Elevation**: 99,75
Water level (m)	**Layer depth (m)**	**Sample**	**Recovery (%)**	**RQD (%)**	**Classification**
Not found	2	0	1	0	Sandy-Silt Fill
		1			
	4	2	5	0	Meta-Sandstone, Sedimentary rock, cream color, friable (C4), significantly altered (A4), fragmented (F5), São Roque Group
		3			
	6	4	5	0	
		5			
	8	6	4	0	
		7			
	10	8	7	0	
		9			
	12	10	7	0	
		11			**Depth determined by the client**

Figure 3: Stratigraphic profile at the location of the borehole drilled at the site.

Each tower leg was supported by a block with four piles. The piles consisted of so-called root-piles, or micropiles, which were circular in cross-section, with 250-mm nominal diameter, and molded in-situ (Figures 4a and 4b). The constructive method involved drilling a cylindrical hole through the fill and meta-sandstone layers using high pressure hydraulics or pneumatics, inserting a reinforcing steel member, and injecting cement grout from the bottom up. Micropiles have mainly been used as foundation elements, as well as for the reinforcement of slopes and existing foundations. The foundation element tested belonged to foundation block "B1", so that the distance between the borehole and the element tested was 1.1 m (Figure 2b).



(a)



(b)

Figure 4: Foundation block detail: (a) plan view of a block, and (b) elevation of the block depicting two root-piles.

INDUCTION LOGGING TESTING

The equipment utilized for performing the IL test consisted of a dual spaced induction probe, model DUN 10290, made by Robertson Geologging (UK), connected to a register Micrologger II that was managed by the Winlogger 1.5 software, a mini winch 150 m and a tripod with encoder velocity transducer, as illustrated in Figure 5.

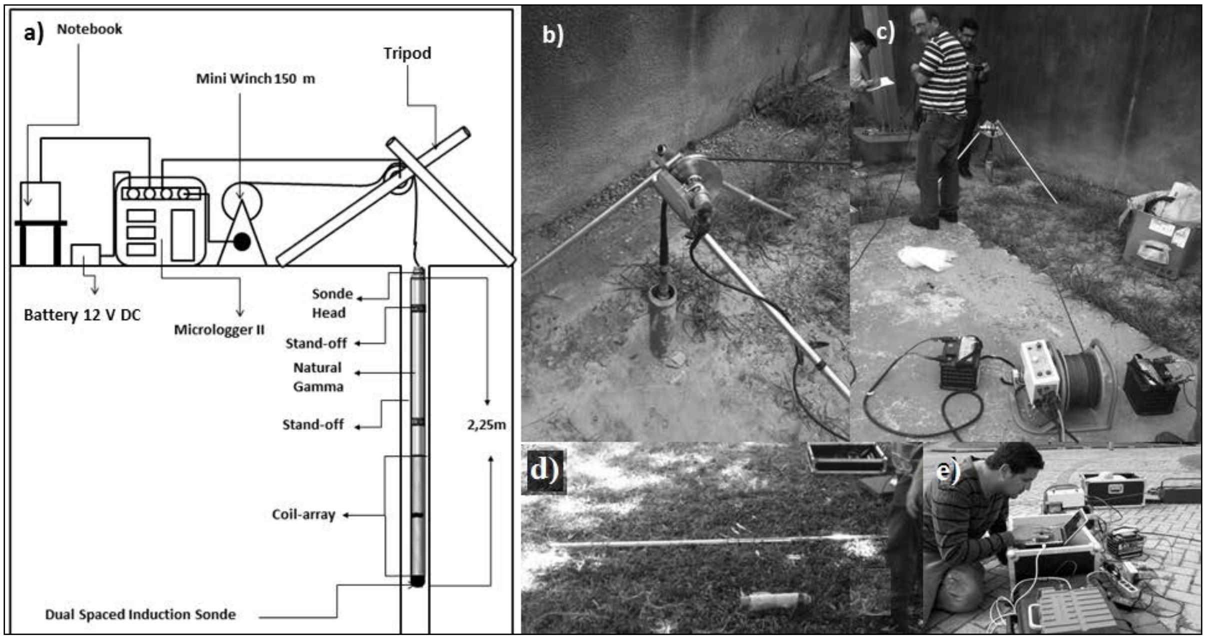


Figure 5: (a) General layout of the IL test equipment-(b) pulley and tripod, (c) mini winch 150 m and batteries, (d) dual spaced induction probe, and (e) micrologger connected to the notebook.

The IL probe utilized had a length of 225 cm, and contained two pairs of transmitting and receiving coils, one located 47 cm from the tip of the probe, where the transmitting coil was installed, and another located 80 cm from the tip, where the receiving coil was installed. The gamma-radiation sensor was located at a distance of 35 cm measured from the top of the sonde and contained a scintillation meter made of sodium iodide crystal. When the crystal was exposed to gamma rays, photons were emitted, which were amplified and converted into electric pulses for register in the form of pulse counts per second.

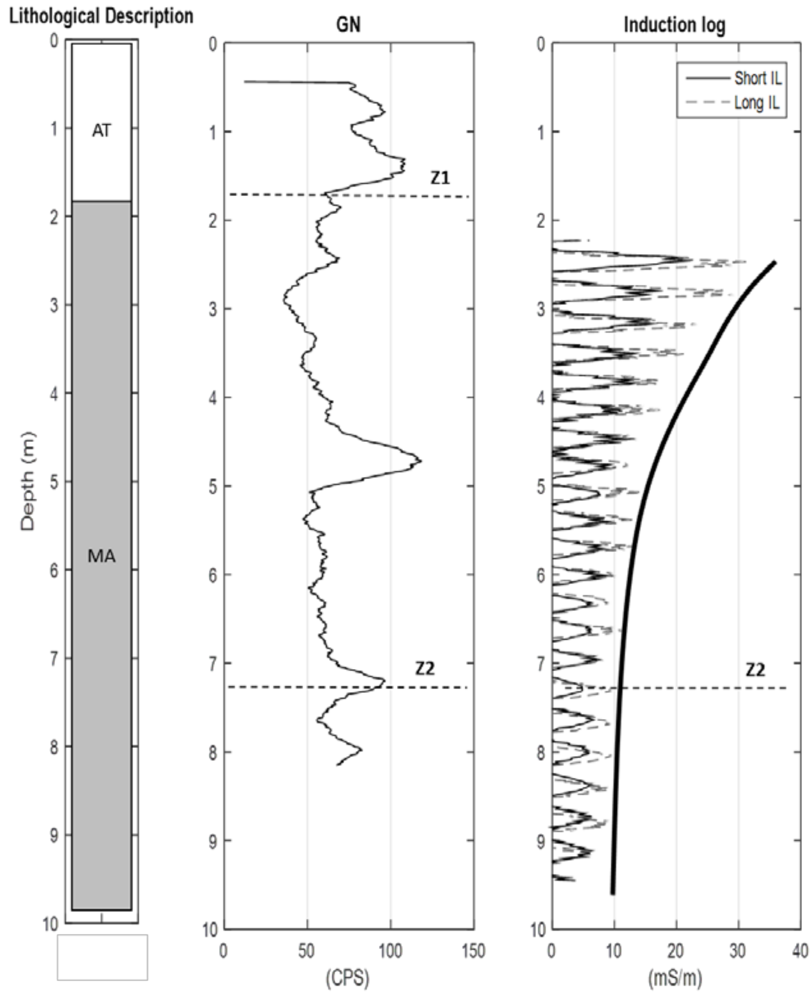
The IL measurements could be taken with the sonde moving downwards or upwards along the borehole. Repeatability between measurements taken using both procedures indicates good quality data. In down hole measures, the surface was used as depth reference, whereas in up hole measures the reference was the base of well. Both conditions can be accommodated by the Micrologger. However, the alternative modes entail different coverage of the sensors. For the gamma-radiation sensor located at 35 cm below the top of the probe, the logs started at an initial depth of 45 cm, since normally the reference level was established when the top of the probe was leveled with ground level. Different coverage also occurs when using the different types of probes (ILM and ILD). Due to the positioning of the sensors, gamma radiation data was collected when the sonde was moved downwards, whereas IL data when moved upwards. This way, each data type was collected under conditions of best possible sensor coverage.

TEST RESULTS AND DISCUSSION

The results obtained with the IL and gamma-radiation sonde are shown in Figure 6. These results include the stratigraphic description of the layers crossed by the probe (Figure 6a), the profile of gamma-radiation, in counts per second (Figure 6b), and the profiles of electric conductivity obtained by induction logging, in $mS.m^{-1}$ (Figure 6c), which included short and long induction logging results (solid and dashed lines) and the amplitude-envelope profile (thicker solid line). The gamma-radiation profile indicated variations between 20 and ~ 120 CPS, whereas the induction logging profiles indicated variations between ~ 0 and 30 $mS\ m^{-1}$.

As shown in Figure 6b, an analysis of the gamma-radiation profile indicated that above the "Z1" level the count numbers ranged between 75 and 100 CPS, whereas below this level the counts ranged between 50 and 100 CPS, with a peak near 120 CPS. The "Z1" level indicates the contact between the fill layer and the meta-sandstone. The acronyms in Figure 6a correspond to "AT" for anthropogenic material (fill), and "MA" for meta-sandstone. The gradual variations in CPS below the "Z1" level suggest texture or clay-content variations in the layer. The CPS variations are interpreted as being inherent to the material and not affected by the foundation element, with no evidence that the longitudinal reinforcement of the foundation element might have affected the gamma-radiation counts, which, in general, are more affected by the materials (soils and rocks) surrounding the borehole.

As shown in Figure 6c, the short and long induction-logging profiles displayed an oscillatory pattern. On the other hand, the IL amplitude envelope displayed a decaying pattern following approximately an exponential decay. With depth, the envelope amplitude declined from a maximum value of ~ 35 $mS.m^{-1}$ to an approximately constant value of 10 $mS.m^{-1}$ below a depth marked in Figure 6c as "Z2". The fact that beyond this depth the amplitude envelope remained at a constant value indicates that "Z2" corresponds to the position of the end of the foundation element, which, in this case, occurs at a depth of 7.0 - 7.5 m.



(a) (b) (c)

Figure 6: Induction and gamma-natural logging results: (a) lithological description, (b) gamma-natural profile in counts per second, and (c) induction-logging profiles in $mS.m^{-1}$.

The exponential-decay pattern with depth observed in the amplitude envelope above the "Z2" level was not expected. The more traditional, expected IL amplitude-envelope results would be the electrical conductivity values to remain approximately constant along the foundation length, and to decline abruptly at the end of the foundation element. This behavior would be justifiable based on the fact that the metallic reinforcement in the foundation element has a much higher electrical conductivity than the surrounding soil or rock (meta-sandstone).

Preliminary tests conducted at a different site helped explain the reason why the amplitude envelope was found to decline exponentially with depth in Figure 6c. These tests allowed to identify the interference of electromagnetic waves (plane waves) generated at the surface - probably by the antennas on the telecommunication tower itself - on the results. Given that the electromagnetic field generated by the sonde is not expected to decay with depth, the results in Figure 6c indicate that the field generated by the sonde may be considered negligible in comparison to the surface field generated by the antennas. If confirmed, this hypothesis indicates that the sonde would stop working as a magnetic-field inducer to act only as a receptor. Currently, there is not a clear explanation to why the amplitude envelope would remain at a constant value at the depth of the foundation element. One hypothesis is that the magnetic field generated at the surface would suffer an influence from a field irradiated by the metallic structure, such that below the end of the structure the sonde would show an attenuation of the field irradiated by the metallic structure.

In order to confirm these hypotheses, it would be necessary to conduct additional measurements, such as carry out measurements along time with the probe in the air and then at every meter in depth, also analyzing the spectral content of these measurements and check if there are differences in the obtained spectral contents. The only limitation to these measurements is the sampling rate of the sonde, which will not allow to identify high frequencies (MHz), but only frequencies within the kHz range. Another possible test is to utilize a portable spectral measuring device to measure the spectral content (kHz to MHz) from the surface down to the bottom of the borehole. Of the signal, the part that attenuates with depth should show a shift to lower frequencies, whereas the part that is irradiated by the foundation element should maintain the frequency peak, attenuating only below the base of the foundation element.

CONCLUSIONS

The use of the IL tests allowed to estimate with good precision the depth of a foundation element consisting of a 250-mm diameter root-pile partially embedded in a profile consisting predominantly of friable and extremely altered meta-sandstone rock. Emphasis is placed on the fact that, under this type of geologic/geotechnical setting, different types of non-destructive tests (NDT) are subject to limitations and likely unable to achieve the goal of determining the foundation depth.

With respect to the induction logging (IL) test, more promising results than those shown in this article might have been achieved had the borehole been located closer to the foundation element, i.e., within a distance of less than 0.5 m from the element being tested. Under this condition, the non-linearity of the electromagnetic signal in a terrain of high electric resistivity could have been better evaluated, as well as the behavior of gamma-radiation in the presence of the longitudinal steel reinforcement of the foundation element.

For future work, factors that interfere in good quality signal acquisition will be further assessed for each test, procedures to enhance the consistency of the analyses will be studied and, finally, the consistency of the results under different geological settings and foundation typologies will be evaluated.

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REFERENCES

1. Keys, W. S. (1989). Borehole Geophysics Applied to Ground-water Investigations, National Water Well Association, Dublin, OH, USA, 314 p.

2. Luthi, S. M. (2001). Geological Well Logs: Use in Reservoir Modeling, Schlumberger, Log Interpretation, II, Aplications: Schulumberger Ltd., Ed. Springer New York, NY, USA, 116 p.

3. Mondelli, G. (2008). Integração de diferentes técnicas de investigação para avaliação da poluição e contaminação de uma área de disposição de resíduos sólidos urbanos. Doctorate Thesis, Escola de Engenharia de São Carlos, University of São Paulo, São Carlos, Brazil, 345 p.

4. McNeill, J. D. (1980). Electromagnetic terrain conductivity measurement at low induction number. Geonics Limited. Technical Note TN-6, Ontario, Canada, 15p. Available at http://www.geonics.com.

5. Scott, J. H.; Petersen, J. K.; Osterkamp, T. E.; Kawasaki, K. (1986). Interpretation of Geophysical Well Logs in Permafrost. U.S. Departament of Energy, U.S. Geological Survey, Denver, CO, USA, 130 p.

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