Laboratory Modeling of Geoelectric Images of Foundation Piles for Depth Extent Determination.

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ABSTRACT

Laboratory modeling of geoelectric images of foundation piles for depth extent determination was carried out using a model tank. The laboratory modeling involved Self Potential (SP) and electrical resistivity measurements over a set of buried simulated piles (metal, plastic, wooden, and concrete) at shallow depth (2.5 cm) within clay and at deep depth (6 cm) extending into bottom sand. The 2-D electrical imaging technique utilized the dipole-dipole electrode array was adopted with dipole lengths of 2 cm, 4 cm, 6 cm and 8 cm, respectively, and an expansion factor (n) varying from 1 – 5. The dipole data were inverted using the DIPRO for windows software which generated 2-D subsurface electrical images over the buried piles. SP data were acquired along same traverse using measurement intervals earlier mentioned. The SP data were presented as profiles and were interpreted qualitatively and semi-quantitatively

The 2-D resistivity structures showed that for all the pile types and at dipole length of 2 cm, the electrical images were discrete and mostly located outside the pile structure. The images generally gave depth extent of about 0.8 cm which was an underestimation of the actual depth extent. With dipole lengths of 4 cm, 6 cm and` 8 cm, the piles were imaged beneath the pile structures. The images of the piles were superimposed to give a composite image with depth extents of 1.5 cm – 1.8 cm; 2.7 – 3.0 cm; and 2.6 – 3.0 cm at shallow depth (within clay) and 1.8 – 4.0 cm; 2.7 – 5.0 cm and 3.8 – 8 cm at deep depth (extending into bottom sand). The foundation piles displayed relatively low resistivity values irrespective of the structure. The observed SP profiles on simulated piles at shallow and deep depth were characterized by negative trough whose peak values were located at about the middle of the set of piles. The SP anomaly form was generally near-symmetrical to slightly asymmetrical. The estimated depth extent from the SP anomalies varied from 0.9 to 6.62 cm for shallow depth of burial and 1.64 to 5.36 cm for deep depth of burial. The foundation piles were best imaged with a dipole length/station interval that was about half the width of the pile structure for the dipole-dipole array and same station interval for the SP. Depth extent estimations were generally overestimated/underestimated at shallow depth but underestimated at deep depth.

(Keywords: geoelectric images, piles, depth extent)

INTRODUCTION

Many of the older bridges in the Nigeria have no original contract documents available and are rated as scour critical with unknown foundation condition and having no information regarding the type, depth, geometry or materials. However, civil engineers often cannot provide funds for the required investigation with conventional excavation, coring or boring methods to determine unknown bridge foundation depth (Olson et al., 1998). An unknown bridge foundation material property differs from the surrounding geotechnical and hydrological environment. The foundation materials may be steel, wood, concrete or masonry. The differing materials properties and geometries of foundations are the most important factors to be considered to non-destructively determine unknown pile foundation. A wide range of possible geophysical methods are available in the literature which can be used to determine unknown pile foundation depth. However, the choice of geophysical method is usually determined by the geologic set up and the existence of significant contrast in the physical properties of the subsurface layers (Olorunfemi et al., 2000; Olorunfemi et al., 2002). Site accessibility also has an impact on the selection of the non-destructive geophysical methods to determine foundation depth (Olson et al., 1998).

The evaluation of the integrity of heavy structure bridges anchored on pile foundation sometimes require the determination of pile foundation depth, most especially when such information is lost in the archives. Techniques often adopted for the determination of pile foundation depth are both invasive (involving excavation, coring or boring) and non-invasive (involving geophysical methods).This study intends to investigate the effectiveness of 1-D Spontaneous Potential (SP) profile and 2-D Electrical Resistivity Subsurface Imaging in the pile foundation depth estimation, through laboratory modeling. Generally, laboratory model study in geophysics has become a vital tool in interpretation of geophysical data. It is often useful in areas of complex geology, most importantly when the signature produced in the field by a particular effect is to be subjected to further investigation.

MATERIALS AND METHODS

A wooden tank whose dimension is 117 cm long, 70 cm wide and 58 cm deep (Akinluyi, 2000) (Figure 1) was constructed. The interior was lined with polythene to prevent water seepage. The tank was filled with river sand up to 46 cm from the bottom of the tank and overlain with plastic clay with a thickness of 5 cm leaving a clearance of 7 cm from the top of the tank. The sediments within the tank was subsequently saturated with water for effective electrical conductivity. A wooden platform was constructed and drilled to 2 mm diameter at interval of 1 cm for electrode mount and five (5) holes were drilled to 1cm diameter for the positioning of the simulated piles. About 2 mm diameter copper wires were used as electrodes.

The resistivity measurements were made using the ABEM SAS 300C Resistivity Meter. The resistance measured was multiplied by geometric factor of the array used to compute the apparent resistivity. For the SP, total field array was adopted and measurements were taken in the SP mode of the ABEM SAS 300C Resistivity Meter. Three stages of measurements were carried out namely: wall effect test, measurements of electrical responses (SP and resistivity) of the different set of piles (metal, plastic, wooden, and concrete) at shallow depth within clay and measurements of the responses of same set of piles at deeper depth extending into sand. In order to delineate the area within the tank whose apparent resistivity response is least influenced by the resistive wall of the tank, a wall effect test was carried out. The Dipole-Dipole array with an expansion factor of n = 1 was adopted for resistivity measurement at station intervals of 2 cm, 4 cm and 6 cm along the central traverse (2) (Figure 1). Generally the apparent resistivity profiles for the different dipole lengths show relatively uniform resistivity within the area of the tank (0 - 95 cm) where resistivity measurements were made. Subsequent resistivity and SP measurements were therefore limited within the 0 – 95cm with a displacement of 11 cm from the wooden wall at both ends. Laboratory measurements which were carried out along the central traverse (2).

RESULTS AND DISCUSSION

<u>The 2-D Subsurface Electrical Images at Shallow Depth of 2.5 cm</u>

The 2-D electrical images within clay over a set of different simulated piles (metal, plastic, wooden and concrete) with dipole length of 2 cm showed resistivity variations of between 4 – 35 ohm-m; 2 – 28 ohm-m; 4 – 60 ohm and 5 – 70 ohm-m respectively as shown in (Figure 2). The resistivity ranges were typical of clay. The variation in resistivity values may be due to variations in the degree of water saturation in the clay. The images with this dipole length were discrete and mostly located outside the pile structure with a depth extent of about 0.8 cm which is an underestimation of the 2.5 cm actual depth extent.

With dipole length of 4 cm (Figure 3), the resistivity variations for the pile types were between 3 – 136 ohm-m; 4 – 637 ohm-m; 3 – 1610 ohm-m and 4 – 643 ohm-m. The current with the dipole length of 4 cm may have penetrated through the upper clay into the bottom sand. The piles were imaged as anomalously low resistivity (<10 ohm-m) zone with depth extent of about 1.5 cm – 1.8 cm. It was expected that the piles (with the exception of the metal type) should generate a relatively high resistivity image within a low resistivity clay host rock. The inverse low resistivity image is therefore suspected to be due to the screening effect of the very low resistivity plastic clay.

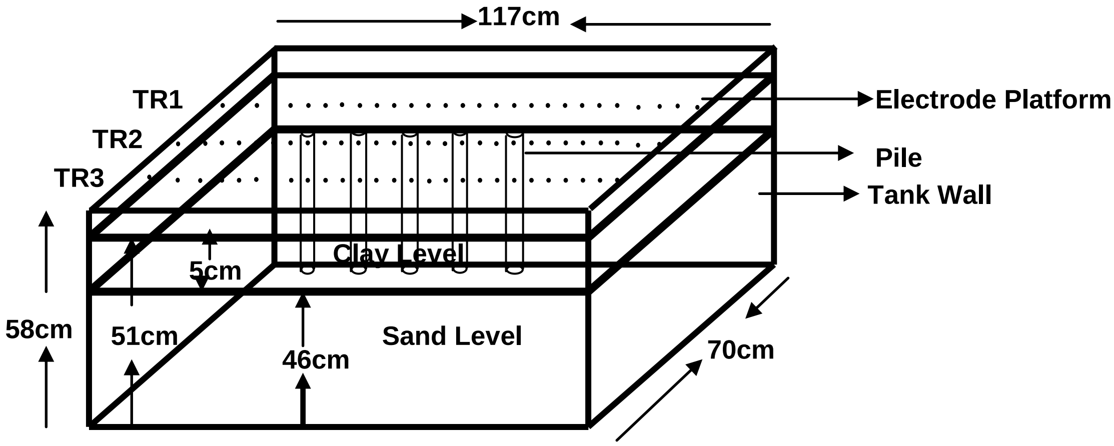

Figure 1: Schematic Laboratory Model Tank showing Measurement Traverse TR2 (end - end pile of 13cm).

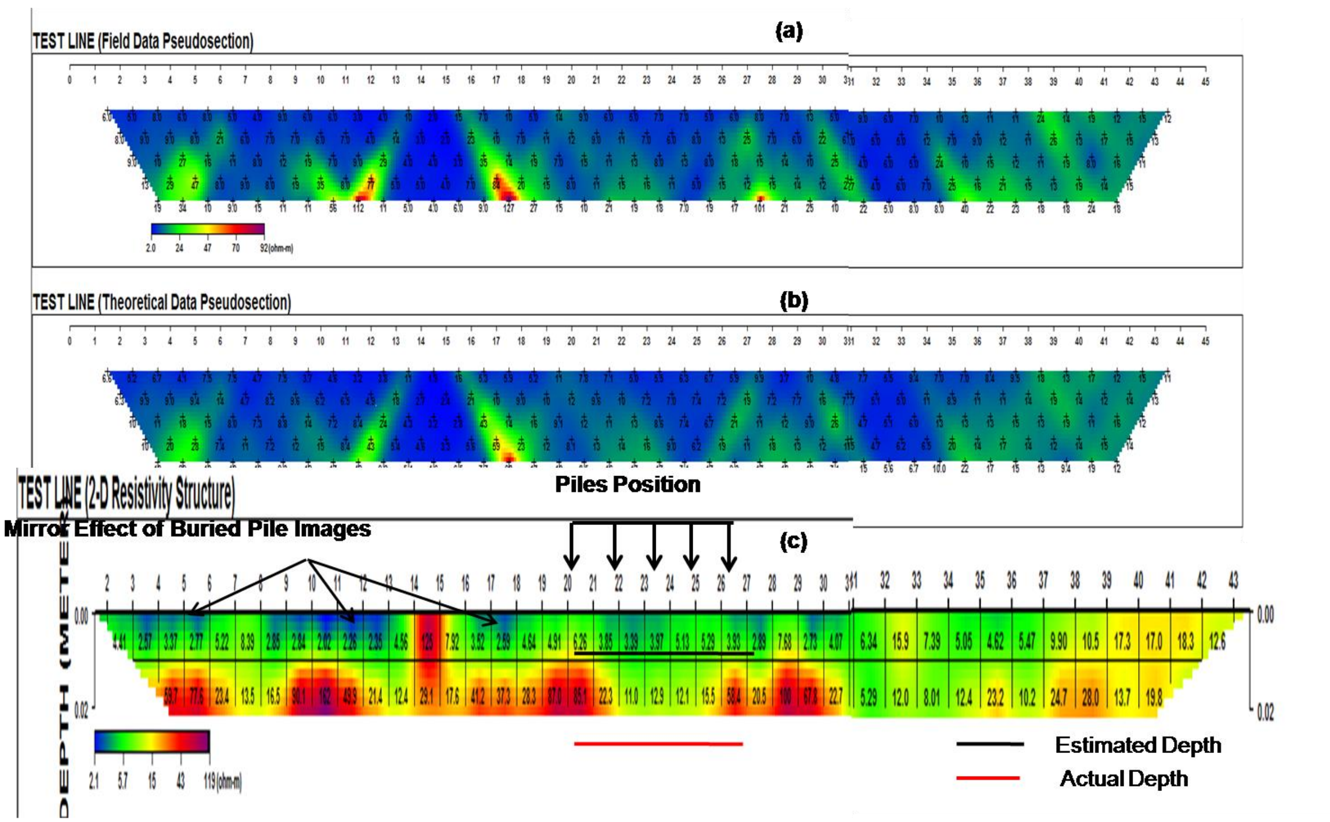

Figure 2: Representative Dipole-Dipole Pseudosection along Traverse 2 with Dipole Length of 2 cm (a) Observed Data (b) Theoretical Data (c) 2-D Resistivity Structure - Shallow Depth of Burial (Concrete Piles)

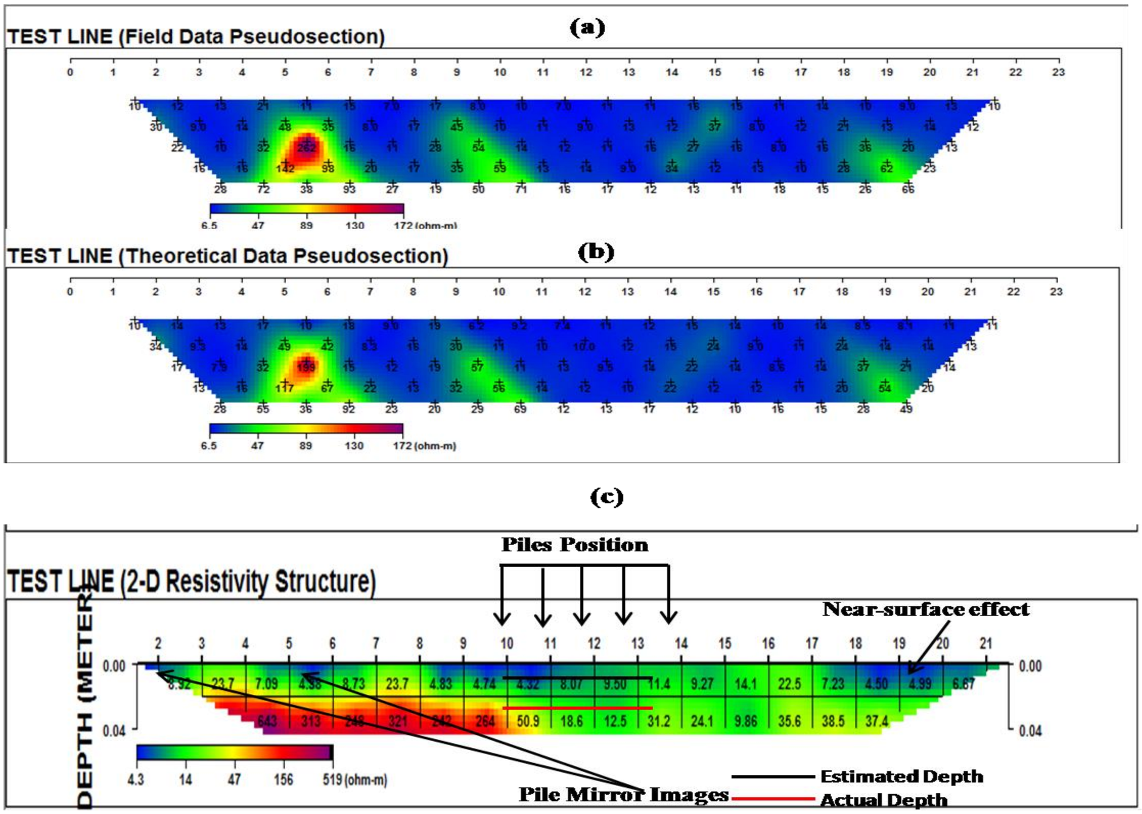

Figure 3: Representative Dipole-Dipole Pseudosection along Traverse 2 with Dipole Length of 4 cm (a) Observed Data (b) Theoretical Data (c) 2-D Resistivity Structure - Shallow Depth of Burial (Concrete Piles).

The composite nature of the electrical images of the pile structures rather than discrete images of the individual buried piles may be due to the fact that the measurement spacing (4 cm) is larger than the interval of 2 cm between two adjacent piles. The resistivity variations of different pile materials with dipole length of 6 cm are 8 – 179 ohm-m; 6 – 643 ohm-m; 8 – 330ohm-m and 8 – 481ohm-m. The piles were imaged compositely as anomalously low resistivity zone (<12 ohm-m) (Figure 4) with depth range of 2.6 – 2.7 cm.

The 2-D electrical images with dipole length and measurement station of 8 cm showed resistivity variations of between 12 – 226 ohm-m; 11 – 204 ohm-m; 12 – 262 ohm-m and 7 – 286 ohm-m. The piles were imaged as low resistivity zone (<17 ohm-m) in (Figure 5). Estimated pile depth extent ranged from 2.6 – 3.0 cm. (see Table 1)

The 2-D Subsurface Electrical Images at Deep Depth of 6 cm

The 2-D electrical images over a set of simulated piles with dipole length of 2 cm (Figure 6) showed resistivity variations of 3 – 137 ohm-m; 3 – 300 ohm-m; 2 – 140 ohm-m and 2 – 35 ohm-m. The buried piles displayed relatively low resistivity values (<5 ohm-m).The images with the above dipole length were discrete and mostly located outside the pile structure. The images gave underestimated depth extent of about 0.8 cm. The resistivity variations with dipole length of 4 cm (Figure 7) are 4 – 464 ohm-m; 4 – 668 ohm-m; 3 – 697 ohm-m and 3 – 963 ohm-m. The buried structures were imaged as an anomalously low resistivity (<12 ohm-m) zone with estimated depth extent of between 1.8 and 4.0 cm.

With dipole length of 6 cm (Figure 8), resistivity values of 8 – 431 ohm-m; 6 – 247 ohm-m; 6 – 1098 ohm-m and 3 – 963 ohm-m were recorded. The buried pile structures were imaged as an anomalously low resistivity (<12 ohm-m). The estimated pile depth extent ranged from 2.7 – 5.0 cm.

The resistivity variations with dipole length of 8 cm (Figure 9) are 12 – 91 ohm-m; 10 – 113 ohm-m; 10 – 612 ohm-m and 9 – 341 ohm-m. The buried structures were imaged as relatively low resistivity (< 15 ohm-m) medium. The estimated pile depth extent ranged from 3.8 – 8 cm. (see Table 2).

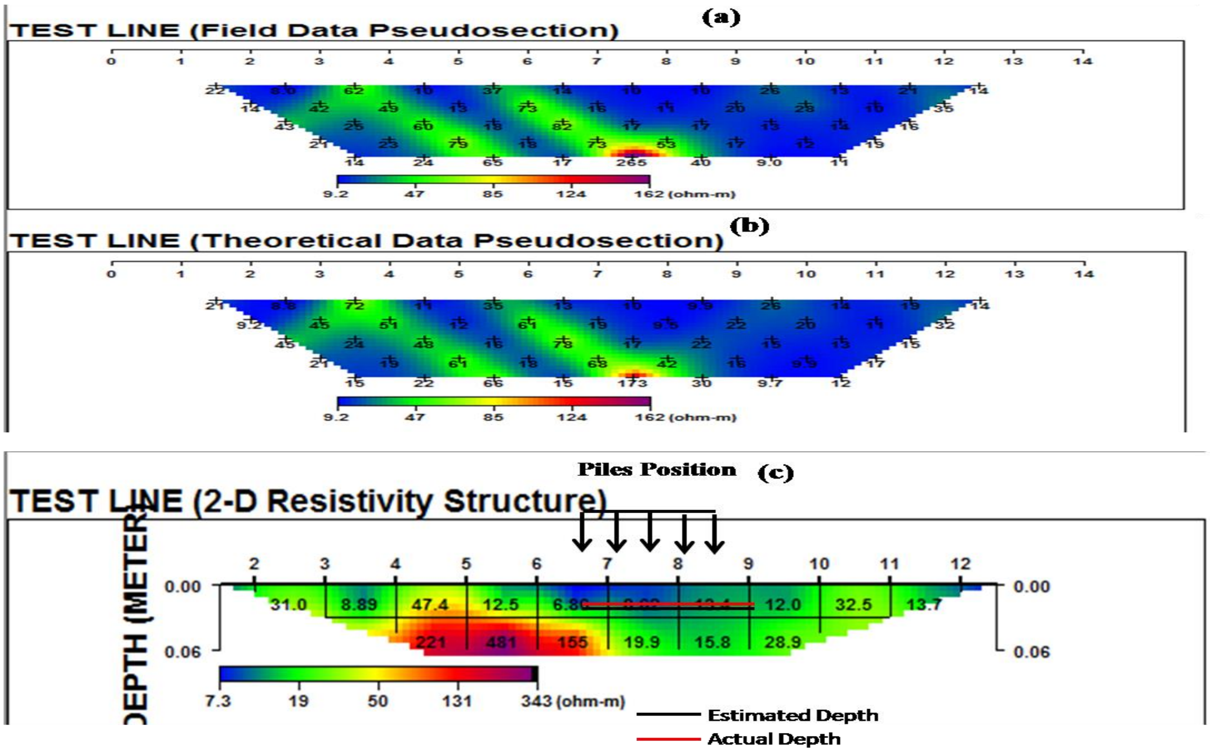

Figure 4: Representative Dipole-Dipole Pseudosection along Traverse 2 with Dipole Length of 6 cm (a) Observed Data (b) Theoretical Data (c) 2-D Resistivity Structure - Shallow Depth of Burial (Concrete Piles).

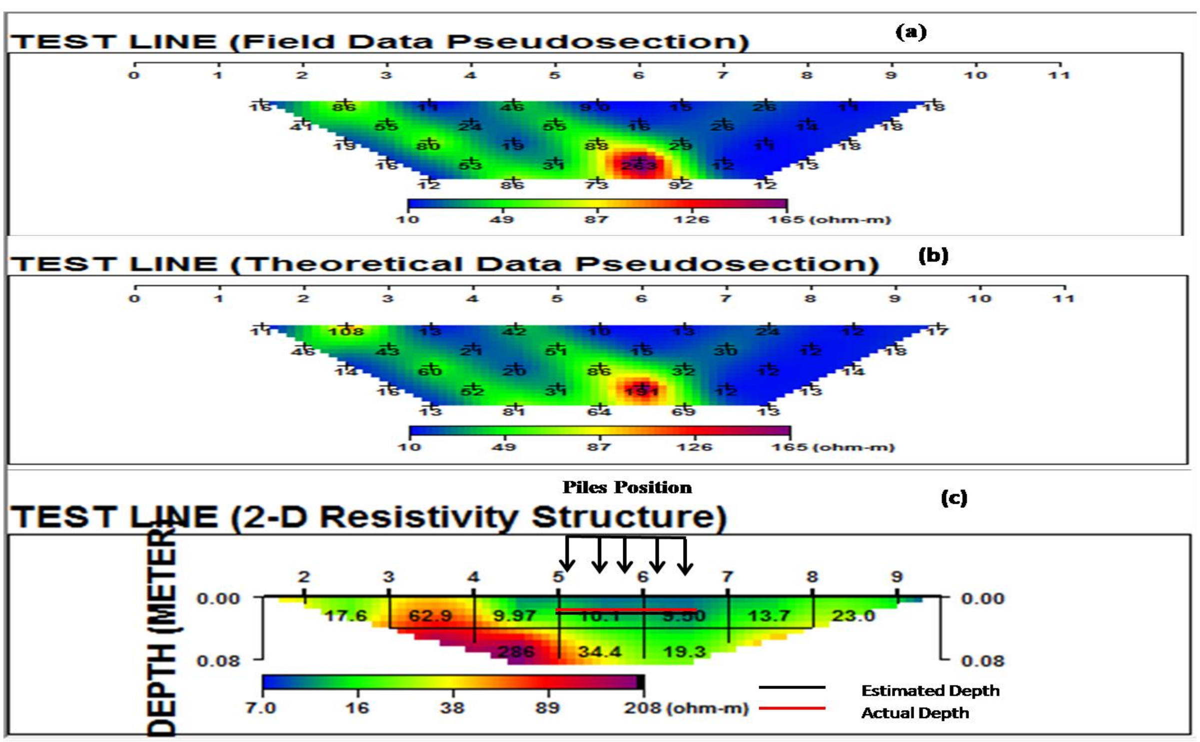

Figure 5: Representative Dipole-Dipole Pseudosection along Traverse 2 with Dipole Length of 8 cm (a) Observed Data (b) Theoretical Data (c) 2-D Resistivity Structure - Shallow Depth of Burial (Concrete Piles).

Table 1: Apparent Resistivity Responses of Dipole-Dipole Pseudosections at Various Measurement Intervals Over Different Set of Simulated Piles at Shallow Depth Within Clay.

PILE TYPE	DIPOLE LENGTH (cm)	SIMULATED DEPTH EXTENT (cm)	IMAGE RESOLUTION	ESTIMATED DEPTH EXTENT (cm)	% DEVIATION IN DEPTH
METAL	2	2.5	Poor	0.8	- 68.0
	4	2.5	Poor	1.8	- 28.0
	6	2.5	Fairly Good	2.6	+4.0
	8	2.5	Fair	2.7	+8.0
PLASTIC	2	2.5	Poor	0.8	- 68.0
	4	2.5	Fairly Good	1.8	- 28.0
	6	2.5	Good	2.7	+8.0
	8	2.5	Fair	3.0	+20.0
WOODEN	2	2.5	Poor	0.8	- 68.0
	4	2.5	Fairly Good	1.8	- 28.0
	6	2.5	Good	2.7	+8.0
	8	2.5	Good	2.7	+8.0
CONCRETE	2	2.5	Poor	0.8	- 68.0
	4	2.5	Fairly Good	1.5	- 40 .0
	6	2.5	Good	2.7	+8.0
	8	2.5	Fairly Good	2.6	+4.0

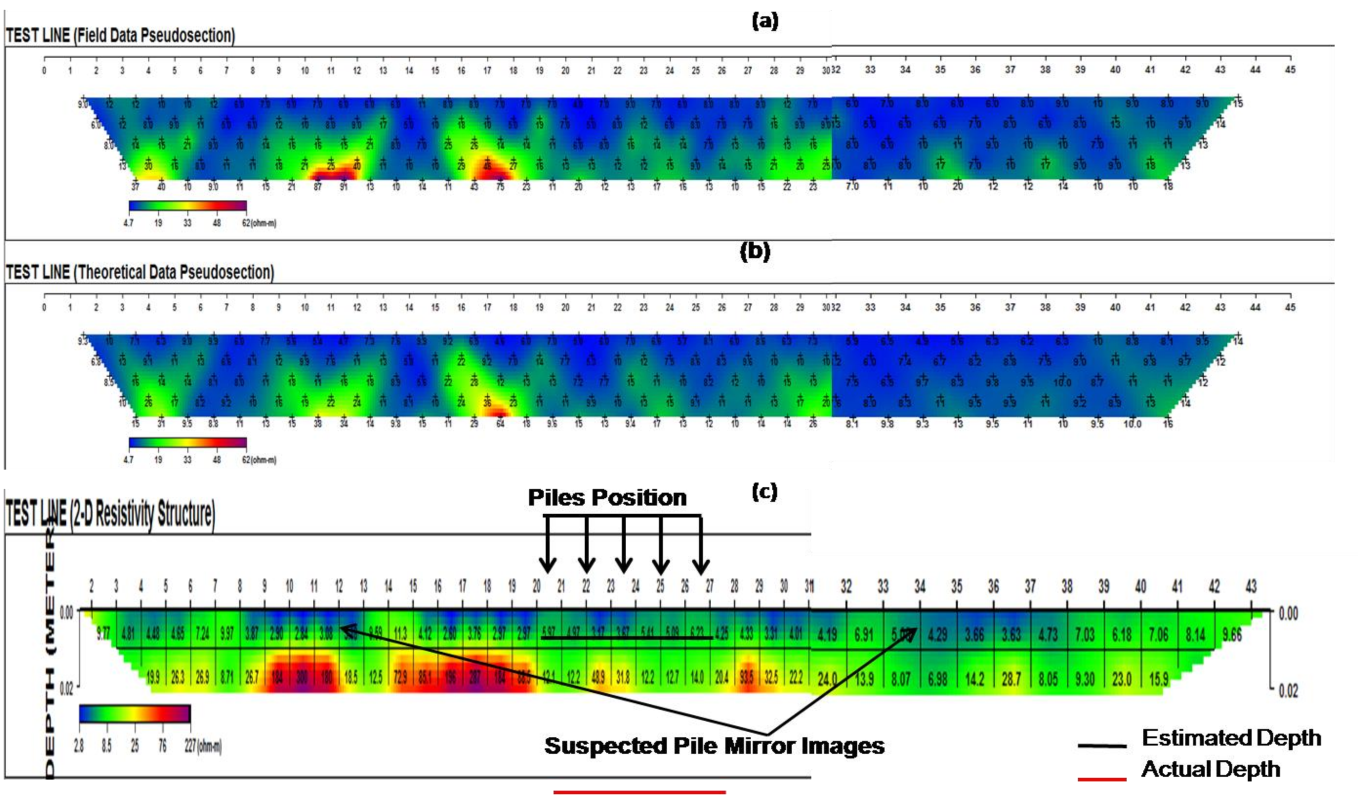

Figure 6: Representative Dipole-Dipole Pseudosection along Traverse 2 with Dipole Length of 2 cm (a) Observed Data (b) Theoretical Data (c) 2-D Resistivity Structure - Deep Depth of Burial (Concrete Piles).

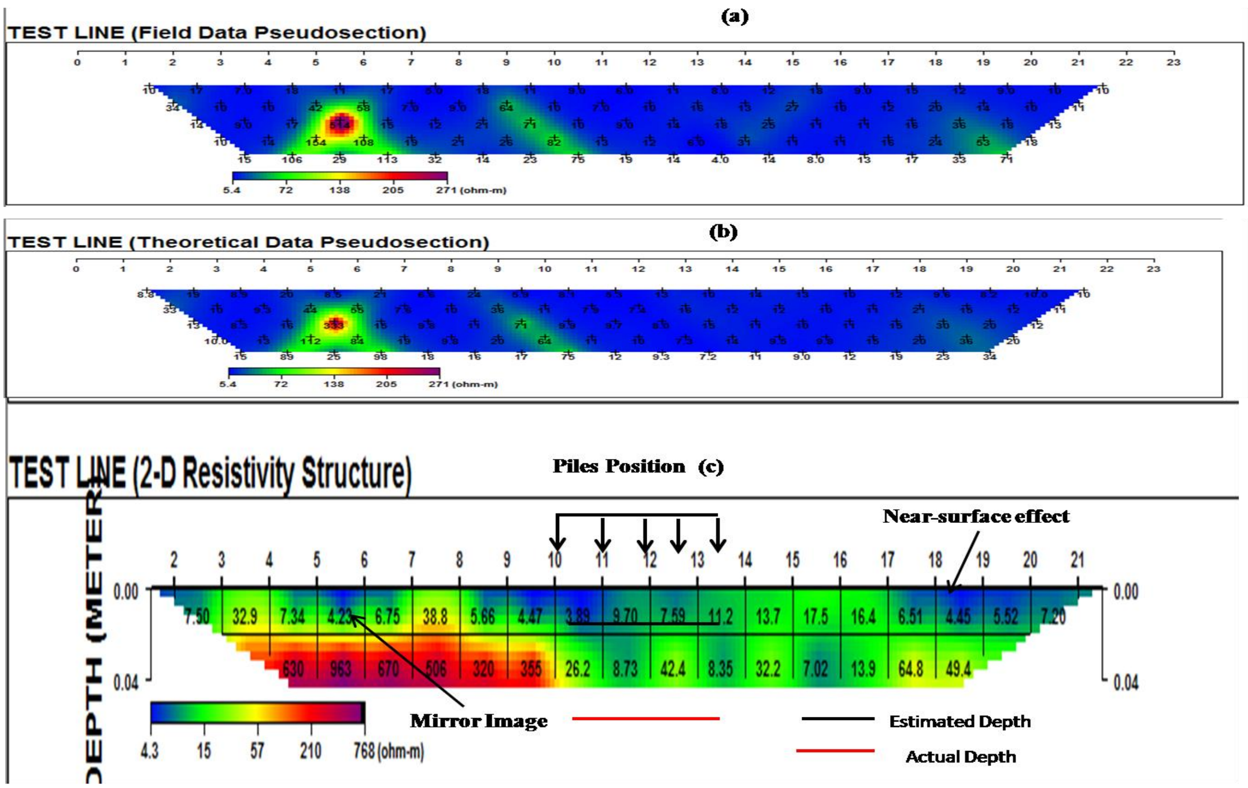

Figure 7: Representative Dipole-Dipole Pseudosection along Traverse 2 with Dipole Length of 4 cm (a) Observed Data (b) Theoretical Data (c) 2-D Resistivity Structure - Deep Depth of Burial (Concrete Piles).

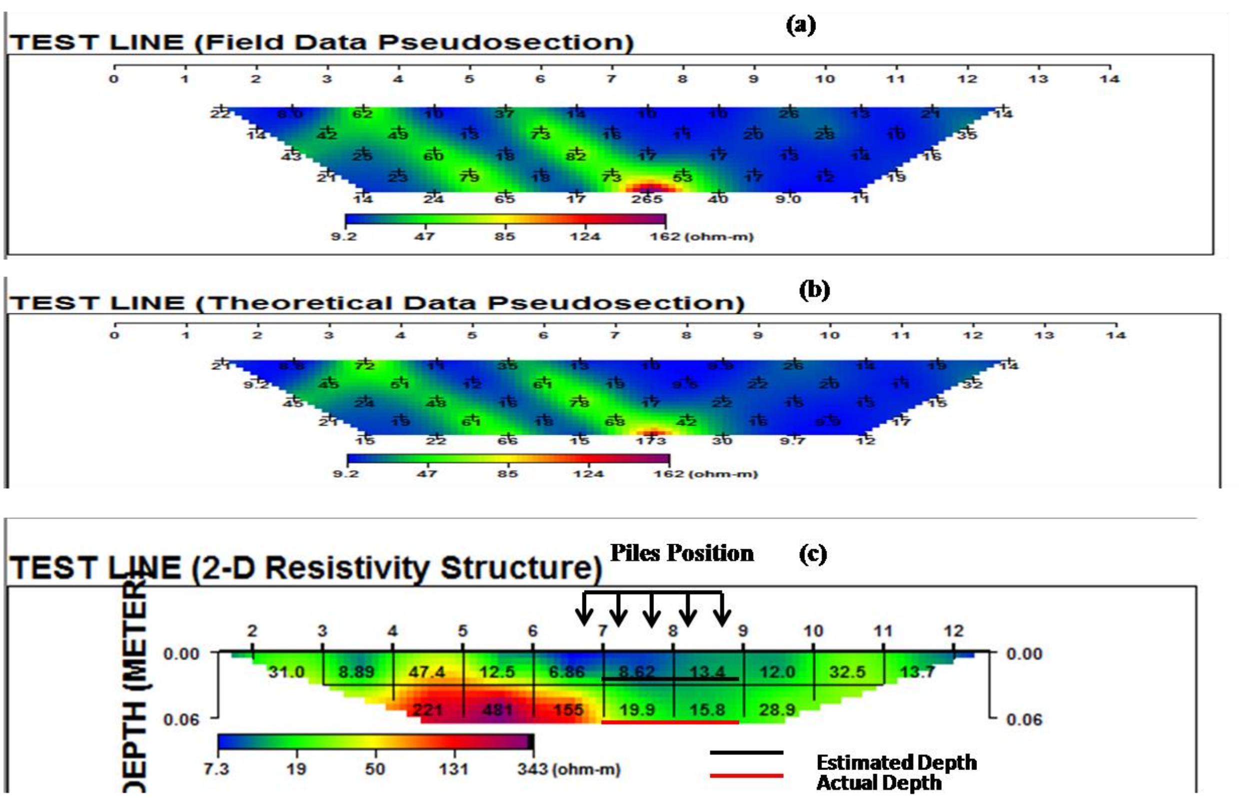

Figure 8: Representative Dipole-Dipole Pseudosection along Traverse 2 with Dipole Length of 6 cm (a) Observed Data (b) Theoretical Data (c) 2-D Resistivity Structure - Deep Depth of Burial (Concrete Piles).

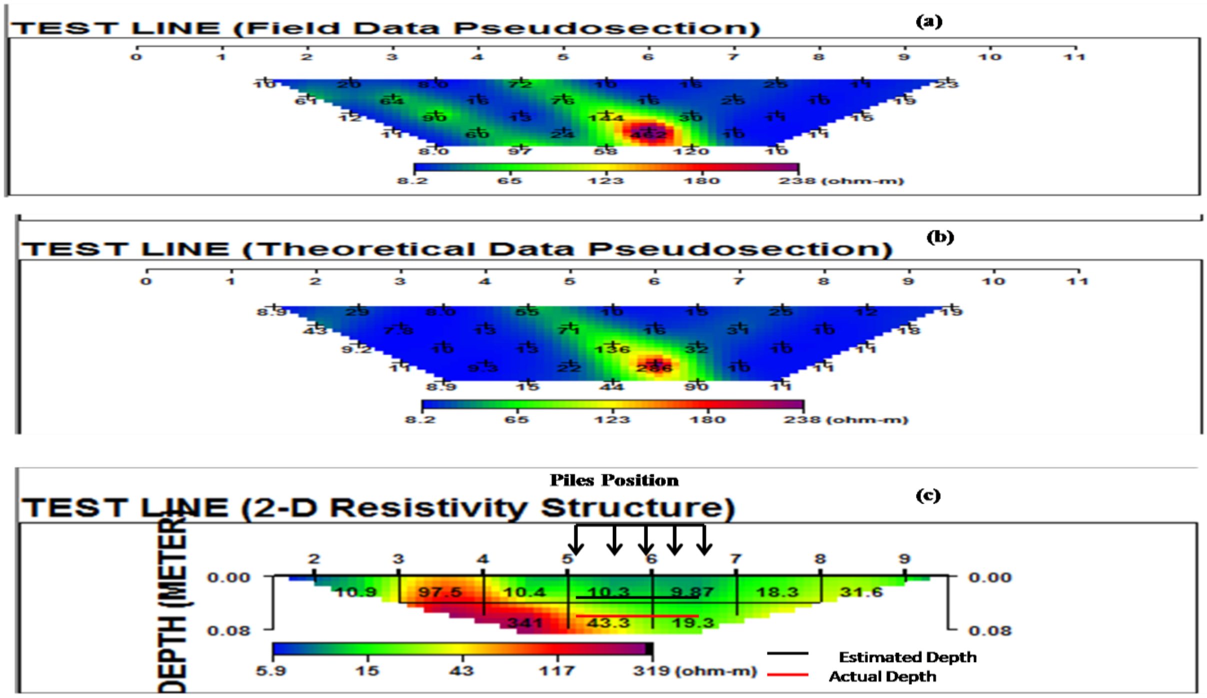

Figure 9: Representative Dipole-Dipole Pseudosection along Traverse 2 with Dipole Length of 8 cm (a) Observed Data (b) Theoretical Data (c) 2-D Resistivity Structure - Deep Depth of Burial (Concrete Piles).

Table 2: Apparent Resistivity Responses of Dipole-Dipole Pseudosections at Various Measurement Intervals Over Different Set of Simulated Piles at Deep Depth Within Clay.

PILE TYPE	DIPOLE LENGTH (cm)	SIMULATED DEPTH EXTENT (cm)	IMAGE RESOLUTION	ESTIMATED DEPTH EXTENT (cm)	% DEVIATION IN DEPTH
METAL	2	6	Poor	0.8	- 86.7
	4	6	Poor	1.8	- 70.0
	6	6	Fairly Good	3.0	- 50.0
	8	6	Good	3.8	- 36.7
PLASTIC	2	6	Poor	0.8	- 86.7
	4	6	Poor	1.8	-70.0
	6	6	Fairly Good	2.8	- 53.3
	8	6	Fairly Good	3.8	- 36.7
WOODEN	2	6	Poor	0.8	- 86.7
	4	6	Poor	1.8	- 70.0
	6	6	Fairly Good	2.6	- 56.7
	8	6	Good	8.0	+ 33.3
CONCRETE	2	6	Poor	0.8	- 86.7
	4	6	Fairly Good	4.0	- 33.3
	6	6	Good	3.0	- 50.0
	8	6	Good	4.0	- 33.3

QUALITATIVE ANALYSIS OF SP PROFILES

SP Profiles over Set of Simulated Piles (metal, plastic, wooden and concrete) at Shallow Depth of 2.5 cm

The SP profiles with station intervals of 2, 4, 6, and 8 cm for piles buried at shallow depth extent showed potential values ranging from +30 to – 56 mV over different simulated piles. The profiles were generally characterized by negative trough whose peak amplitude values were located at about the middle of the set of piles, indicating a composite anomaly. The SP anomaly frequencies decrease with increase in station interval. The SP anomaly form was generally near-symmetrical to slightly asymmetrical as shown in (Figure 10).

SP Profiles over Set of Simulated Piles (metal, plastic, wooden and concrete) at Deep Depth of 6 cm

The observed SP profiles for piles with deep depth extent (Figure 11) for same measurement intervals showed potential values ranging from +35 to – 38 mV. The pile structure was located beneath negative SP trough with peak amplitude situated at about the center of pile structure. The anomaly frequencies generally decreased with increase in station interval. The SP anomaly form was generally near-symmetrical to slightly asymmetrical.

SEMI-QUANTITATIVE ANAYSIS OF SP PROFILES

The total field SP anomaly can be interpreted semi-quantitatively for the determination of depth (Z) to the top of a causative body by adopting the half width technique (Adeyemi et al., 2006). The half width, $X_{1/2}$ (or half wavelength) – the distance from the origin at which the anomaly amplitude is half its maximum amplitude is related to the depth of burial Z, by the equation

$$X_{1/2} = \sqrt{3}\, Z = 1.73\, Z \quad \textbf{(1)}$$

or

$$Z = 0.58X_{1/2} \quad \textbf{(2)}$$

However, in the present study, the focus is on the depth extent (or depth of burial) of the pile and hence the above equation may not be applicable. However, by a rule of thumb the above equation was applied in a modified form as:

$$Z' = 0.63X_{1/2} \quad \textbf{(3)}$$

Where Z' is the depth extent from ground level. The estimated depth extent values for the different pile structures are contained in Tables 3 and 4.

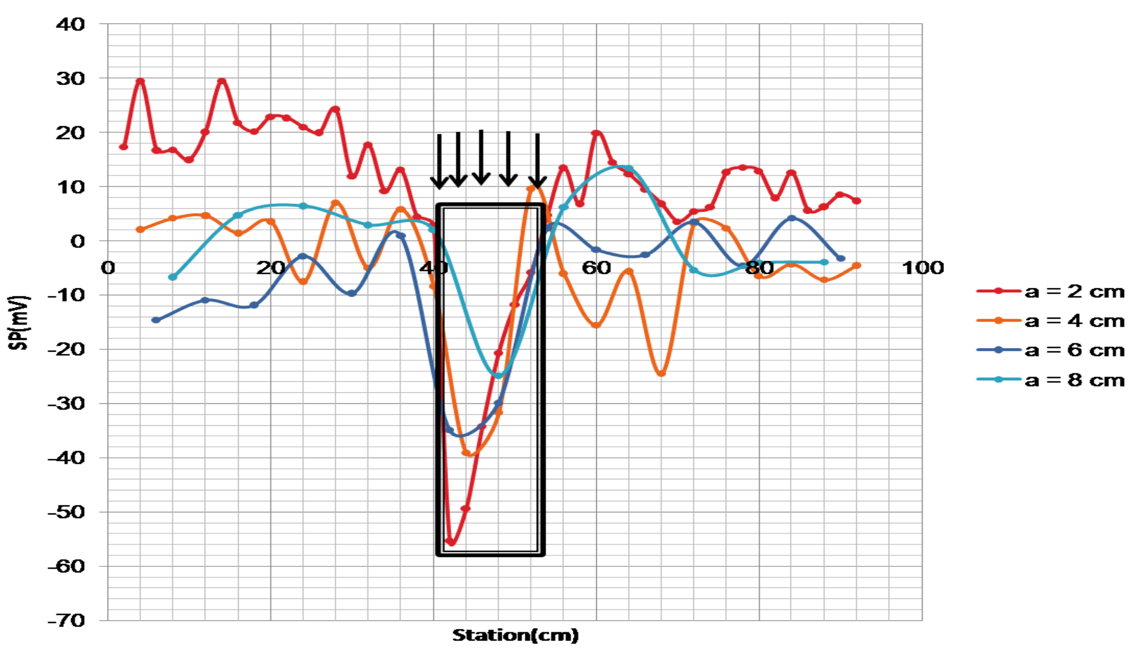

Figure 10: Stacked SP Profiles Over Simulated Piles at Different Measurement Intervals at Shallow Depth .

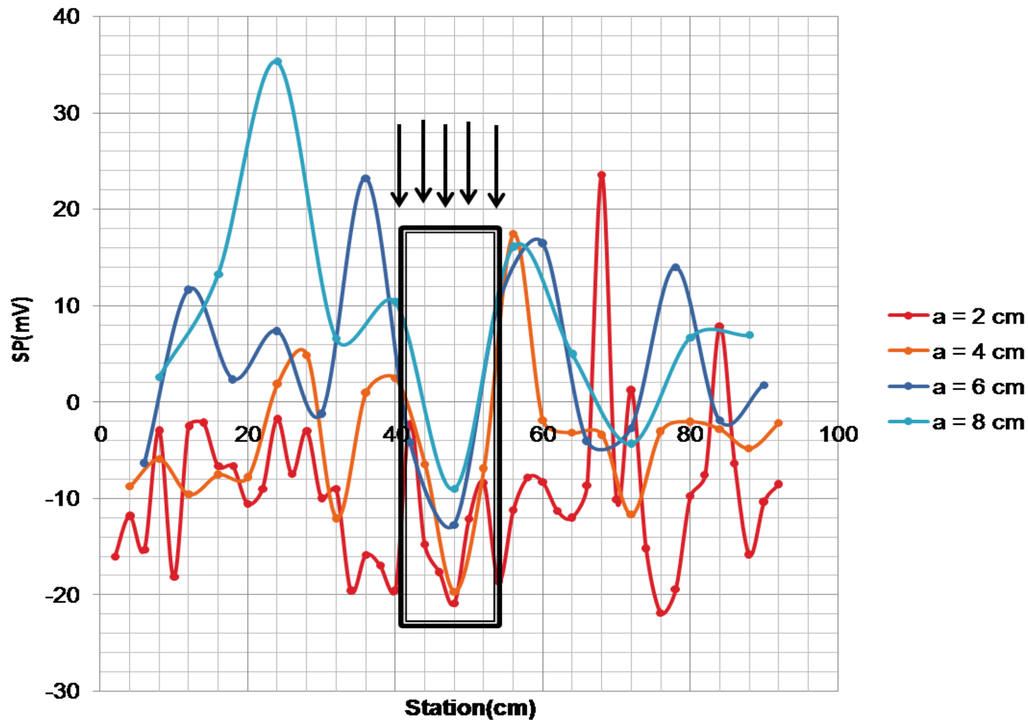

Figure 11: Stacked SP Profiles Over Simulated Piles at Different Measurement Intervals at Deep Depth.

Table 3: Depth Responses of Total Field Array at Various Measurement Intervals Over Different Set of Simulated Piles at Shallow Depth Within Clay.

PILE TYPE	SPACING LENGTH (cm)	$X_{1/2}$ (cm)	SIMULATED DEPTH EXTENT (cm)	ESTIMATED DEPTH EXTENT (cm)	% DEVIATION IN DEPTH
METAL	2	4	2.5	2.52	+0.8
	4	4.9	2.5	3.09	+23.6
	6	5	2.5	3.15	+26.0
PLASTIC	2	1.4	2.5	0.9	- 64.0
	4	4.1	2.5	2.6	+4.0
	6	4.5	2.5	2.84	+13.6
	8	10.5	2.5	6.62	+164.8
WOODEN	2	2.1	2.5	1.32	- 47.2
	4	3.8	2.5	2.4	- 4.0
	6	5.6	2.5	3.5	+40.0
	8	6.6	2.5	4.16	+66.4
CONCRETE	2	3.4	2.5	2.14	- 14.4
	4	4	2.5	2.52	+8.0
	6	5.2	2.5	3.28	+31.2
	8	4.5	2.5	2.84	+13.6

Table 4: Depth Responses of Total Field Array at Various Measurement Intervals Over Different Set of Simulated Piles at Deep Depth Within Clay.

PILE TYPE	SPACING LENGTH (cm)	$X_{1/2}$ (cm)	SIMULATED DEPTH EXTENT (cm)	ESTIMATED DEPTH EXTENT (cm)	% DEVIATION IN DEPTH
METAL	2	4.9	6.0	3.09	- 48.5
	4	4	6.0	2.52	- 58.0
	6	8.5	6.0	5.36	- 10.7
	8	4.3	6.0	2.71	- 54.8
PLASTIC	2	2.7	6.0	1.70	- 71.6
	4	4.4	6.0	2.77	- 53.8
	6	5.8	6.0	3.65	- 39.2
	8	3.6	6.0	2.27	- 62.2
WOODEN	2	2.8	6.0	1.76	- 70.7
	4	3.2	6.0	2.02	- 66.3
	6	7.2	6.0	4.54	- 24.3
	8	4.9	6.0	3.09	- 48.5
CONCRETE	2	2.6	6.0	1.64	-72.7
	4	5.7	6.0	3.59	- 40.2
	6	7.4	6.0	4.66	- 22.3
	8	5.4	6.0	3.40	- 43.3

CONCLUSION

The pile structure (metal, plastic, wood and concrete) was variably imaged by all the dipole lengths and at station intervals 2 cm, 4 cm, 6 cm and 8 cm used. However the best resolving electrical image was obtained across board with dipole length and station interval of 6 cm which is about half the width (13 cm) of the pile structure. For this dipole length and station interval, the depth extent of the pile was slightly overestimated by +4.0% to +8.0% at shallow depth and underestimated by - 50% to – 56.7% at deep depth.

The SP profiles for the station intervals are significantly diagnostic with the middle of the pile structure situated around the peak negative SP troughs. However, SP profiles for station intervals of 4 – 8 cm gave single SP troughs that are near-symmetrical to slightly asymmetrical and amenable to semi-quantitative interpretation.

The estimated depth from SP anomalies against the actual depth extent over the pile structures at measurement intervals of 2, 4, 6 and 8 cm at shallow (2.5 cm) and deep (6.0 cm) depth of burial shows that estimated depths were generally close or slightly overestimated (+8.0% to 40.0% with the exception of two deviations of +64% and 164.8% for plastic pile) at shallow depth of burial and underestimation of – 10% to – 72.7% at deep depth of burial. However for the SP profiles generated for station interval of 6 cm (about half the width of the pile structure), estimated depth extent were overestimated by +13.6% to 40% at shallow depth and underestimated by – 10.7% to – 39.2% at deep depth.

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