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Resistivity response of the earth due to buried cables in the ground at abraka, delta state

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ABSTRACT

Four stations were recently investigated at Abraka using Vertical Electrical Sounding (VES) for detailed studies for the analysis of the resistivity response of the earth due to buried cables (wires) in the ground. The cable is characterized by specified axial impedance and is assumed to be infinite in length. A configuration of a current point source in an infinite region was considered. The result shows that the metal conductor or cable channels a major portion of the current flow thereby leading to profound departures from the apparent resistivity curves calculated from idealized homogeneous and layered structures. It was observed that it is not advisable to carry out VES survey in an area where there are metallic conditions or pipes since they channel part of the current flow and distort the potential field distribution.

Introduction

The resistivity method is an inexpensive and operationally simple method, but its efficiency decreases with depth. It is ideally suited to shallow investigations from the ground surface to 1000m and is more suited to detailed localized studies than to reconnaissance regional work.

To date, the use of resistivity method for ground-water pollution studies has not been very effective. Investigations have been confined to resistivity profiling with an almost total exclusion of sounding. Where sounding have been attempted, they have been interpreted by questionable empirical methods. Nevertheless, the method has considerable potential. The main difficulty anticipated in this application is the cultural noise which accompanies cultural sources of pollution. (Egbai, 1999). Examples of such noise are grounded fences, buried pipes and cables and in homogeneity in land fill areas. Electrical probing of the environment may be influenced unduly by the presence of man-made conductors such as wires, cables and pipes. These axial channel the current flow and distort the potential field distribution (Grant and West, 1965, Keller and Frischknecht ,1966, AP Pin et al 1966, Wheelon 1968, Sunde 1968, Wait and Umashankar 1978). A quantitative understanding of such effects is largely lacking. Some geometry that provides relevant information was analyzed. The aim of this work is to show the theoretical framework for a class of problems that permit an analytical approach to be used.

Conductivity, a measure of water's ability to transmit electrical current, is a gross, indirect measurement of the concentration of ions. Consequently, conductivity can be used to estimate levels of total dissolved solids (TDS), a measurement of the dry mass of dissolved solids in water. Resistivity is the reciprocal of conductivity. Measured resistivities in Earth materials are primarily controlled by the movement of charged ions in pore fluids. Although water itself is not a good conductor of electricity, ground water generally contains dissolved compounds that greatly enhance its ability to conduct electricity. Hence, porosity and fluid saturation tend to dominate electrical resistivity measurements. In addition to pores, fractures within crystalline rock can lead to low resistivities if they are filled with fluids. Resistivity is primarily a function of fluid content. Thus, a common target for electrical surveys is the identification of fluid saturated zones hence the methods are commonly used in engineering and environmental studies for the identification of water table.

The performance of buried power transmission cables in areas subjected to ground deformations is an important engineering consideration for the utility. The performance of buried power transmission cables subjected to permanent relative axial ground displacements was investigated using a full – scale testing facility (Ahmadnia, et al 2008).

Current knowledge on the response of buried power cables subject to ground movement is scarce although there may be findings from investigations performed (by private entities) for specific uses that are either not published and documented, or cannot be generalized to other condition. Due to this lack of alternative approaches pipe – soil interaction models developed for steel pipes (ALA,American Lifeline Alliance, 2001) is analyzing cable configurations.

A testing apparatus that was designed and constructed at the University of British Columbia a (UBC), Vancouver, Canada to conduct full – scale modeling research on pipe – soil interaction problems (Anderson ,Wijewickreme and Ventura 2005, Weerasekara and Wijewickreme 2008) was used by (Wait and Hill 1975, Hill and Wait 1979) in their testing work. The test setup mainly comprise of 3.8m(L), 2.5m(W) and 2.5m(H) soil chamber, hydraulic actuator system, and a data acquisition system.

Some numerical examples based on the theory were presented using Abraka and its environ for the study.

Theory

The theory is based on the work of Wait and Umashankar, 1978.

Nature of the Wire (cable)

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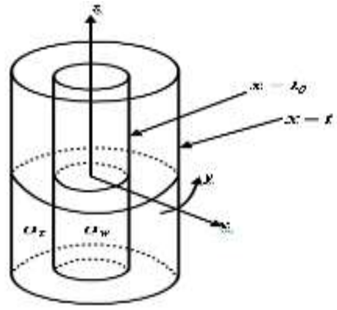


Fig 1: Enlarge coaxial structure of the wire (cable)

Fig. 1: Enlarged coaxial structure of the wire (cable) consisting of a solid centre conductor with a concentric sheath. The cyclinder coordinate system (*x, y, z)* is also shown.

For simplicity, the axial conductor was regarded as a wire (cable). This is modeled as concentric cylinder structure of an infinite length. For a cylindrical coordinate system (x, y, z), the solid center conductor is defined by $-\infty < z < \infty$ and $x < t_0$. The wire was surrounded by a coating of conductivity of Γ_t defined by $-\infty < z < \infty$ and $t_0 < x < t$. The external region of the cable $x > t$ was neglected. An assumption that the fields in the vicinity of the wire are locally uniform due to the azimuthal symmetry prevails $\left(\partial / \partial y = 0 \right)$. The transverse magnetic field (TM) is important since we are interested with axial currents. The electric field components H_y are both functions of *x* and *z*. assuming that the cable is being excited by an external current source such that *Ez* is an odd function about $z = 0$. This shows the Fourier sine integral

$$E_z(z) = \left(\frac{2}{\pi} \right)^{1/2} \int_0^\infty \overline{E}_z(\theta) Sin\theta z d\theta \qquad (1)$$

and its inverse

$$\overline{E}_z(\theta) = \left(\frac{2}{\pi} \right)^{1/2} \int_0^\infty E_z(Z) Sin\theta Z dz \qquad (2)$$

$E_x(z)$ And $H_y(z)$ with corresponding inverse transforms $\overline{E}_x(\theta)$ and $\overline{H}_y(\theta)$ could be written as well. For practical measurement, the time-varying field is utilized. Thus, the fields vary as $exp(iwt)$ where w the angular frequency can be neglected.

If we consider the fields in the central conductor $(x > t_0)$, we can derive these from an electric vector with only a z component $\pi_z(Z)$. Thus

$$E_z(Z) = \left(-y_w^2 + \frac{\partial^2}{\partial z^2} \right) \pi_z(Z) \qquad (3)$$

$$E^x(Z) = \frac{\partial^2 \pi_z(Z)}{\partial x \partial z} \qquad (4)$$

And

$$H_y(Z) = -\sigma_w \frac{\partial \pi_z(Z)}{\partial x} \qquad (5)$$

Where $y_w^2 = i\sigma_w \mu_w w$ where μ_w is the magnetic permeability. If displacement currents are considered, we replace σ_w by $\sigma_w + i\varepsilon_w w$ where ε_w is the permittivity of the central conductor. Similarly,

$$\pi_z(Z) = \left(\frac{2}{\pi} \right)^{1/2} \int_0^\infty \overline{\pi}_z(\theta) Sin\theta z d\theta \qquad (6)$$

Since $\left(\nabla^2 - y_w^2 \right) \pi_z(Z) = 0 \qquad (7)$

For the region $x < x_0$, we can write

$$\overline{\pi}_z(\theta) = C(\theta) I_0(Ux)$$

Where $U = \left(\theta^2 + y_w^2 \right)^{1/2}, C(\theta)$ is an arbitrary function and I_0 is the modified Bessel function that remains finite at $x = 0$.

The following axial impedance $Z_w(\theta)$ of the centre conductor can be written as

$$Z_w(\theta) = \left. \frac{\overline{E}_z(\theta)}{2\pi x H_y(\theta)} \right| x = t_0 = \frac{U I_0(Ut_0)}{2\pi \sigma_w t_0 I_1(Ut_0)} \qquad (9)$$

If $\left| y_w^2 \right| >> \theta^2$, then

$$Z_w(\theta) \approx Z_w = \frac{y_w I_0(y_w t_0)}{2\pi \sigma_w t_0 I_1(y_w t_0)} \qquad (10)$$

If $\left| y_w t_0 \right| << 1$ this reduces to

$$Z_w \approx \frac{1}{\pi \sigma_w t_0^2} \qquad (11)$$

This is the expected D. C. result.

In dealing with the concentric region $t_0 < x < t$, we could proceed in a similar manner. If we utilized the fact that the coating is a relatively poor conductor so that, for all conceivable situations, $|vx| << 1$ where $v = \left(\theta^2 + y_t^2 \right)^{1/2}$, $y_t^2 = i\sigma_t \mu_t w$. Then the simpler form is relevant

$$\overline{\pi}_z = (\theta) \approx A(\theta)[1 + x(\theta) 1_n x] \qquad (12)$$

Where $x(\theta)$ is yet to be determined. Then, for this same region $t_0 < x < t$,

$$\left(\frac{2}{\pi} \right)^{1/2} \overline{E}_z(\theta) \approx -A(\theta)\theta^2 [1 + x(\theta) 1_n x] \qquad (13)$$

And $\left(\frac{2}{\pi} \right)^{1/2} \overline{H}_y(\theta) \approx -\sigma_t x(\theta) A(\theta) / x \qquad (14)$

If (9) holds for $x = t_0$, we can deduce that

$$\left. \frac{\overline{E}_z(\theta)}{2\pi x \overline{H}_x(y)} \right| x = t = Z_t(\theta) \approx Z_w(\theta) + \frac{\theta^2}{2\pi \sigma_t} 1_n \frac{t}{t_0} \qquad (15)$$

Where $Z_t(\theta)$ is the effective impedance (per unit length) of the wire for fields of Z dependence of the form $exp(\pm i\theta z)$. If σ_t is replaced by $\sigma_t + i\varepsilon_t w$ to account for the displacement current in the coating with permittivity ε_t. This approach was accepted by Wait and Hill (1975) and Hill and Wait (1977). It can be used for more complicated cables or wires such as coaxial with metallic sheath. Equation (16) is a function of θ the axial wave number. Z_t is given as $Z_t = \frac{E_z}{I}$ at $x = t$, where *I* is the total current carried by the wire, E_z is the electric field in the z direction.

Response of the wire (cable) to a point current source in an infinite medium

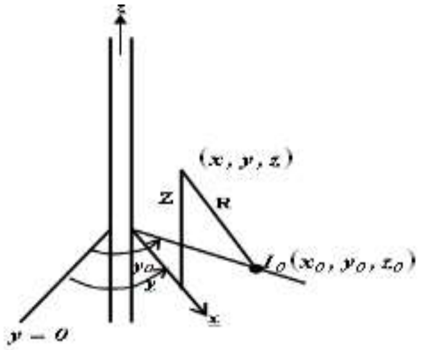


Fig. 2: current source I_0 with cylindrical coordinates (x_0, y_0, z_0) located outside the cable (wire) that is coaxial with the z-axis.

The diagram is as shown in figure 2. If current I_0 is flowing and located in a homogeneous region of infinite region of conductivity σ at (x, y, z) then the problem is to compute the fields at (x, y, z) due to the source in the presence of the wire which is coincident with the z-axis. If we consider the potential fields outside the wire and since all dimensions such as x and x_0 are small compared with the skin depths in the external medium [i.e. x and $x_0 << \delta = \frac{2}{(\sigma\mu_0 w)^{1/2}}$]. Here the inductive coupling of the source current circuit is not considered.

Considering the above stated conditions, the primary potential V_p of the source current, in the absence of the wire, is given by

$$V_p = I_0 / 4\pi\sigma R \qquad (16)$$

Where

$$R = \left[x^2 + x_0^2 - 2xx_0 Cos(y - y_0) + Z^2\right]^{1/2} \qquad (17)$$

If we now use the known integral formula [Wheelon (1968)].

$$\frac{2}{\pi}\int_0^\infty L_0(\beta x) Cos\,\alpha x dx = \frac{1}{(\alpha^2 + \beta^2)^{1/2}} \qquad (18)$$

for $\beta > 0$, we can write

$$V_p = \frac{I_0}{2\pi^2\sigma}\int_0^\infty L_0\left\{\theta\left[x^2 + x_0^2 - 2xx_0 Cos(y - y_0)\right]^{1/2}\right\} Cos\theta Z d\theta \qquad (19)$$

Total potential is given by

$$V = V_p + V_s$$

Where V_s is the secondary potential due to the wire current

$$V_s = \frac{I_0}{2\pi^2\sigma}\int_0^\infty L_0(\theta y) P(\theta) Cos\theta Z d\theta \qquad (20)$$

$\nabla^2 V_s = 0$ For $y > t$ and y independence of V_s is appropriate when $x_0 >> t$. $P(\theta)$ Is yet to be determined.

The corresponding Hert potential π_z^s has the form

$$\pi_z^s = \int_0^\infty F(\theta) L_0(\theta y) Sin\theta Z d\theta \qquad (21)$$

If $\theta F(\theta) = \frac{-I_0 P(\theta)}{(2\pi^2\sigma)}$, then

$$\pi_z^s = \frac{-I_0}{2\pi^2\sigma}\int_0^\infty P(\theta) L_0(\theta y)\frac{Sin\theta Z}{\theta} d\theta \qquad (22)$$

If $V_s = -\partial\pi_z^s / \partial Z$, the magnetic field of the wire currents could be obtained from

$$H_y^s(Z) = -\sigma\frac{\partial\pi_z^s}{\partial x} = \frac{-I_0}{2\pi^2}\int_0^\infty P(\theta) Sin\theta Z L_0(\theta x) d\theta \qquad (23)$$

If we use the identity $L_0(\rho) = -L_1(\rho)$.

The actual wire current $I_{(z)}$ is given by

$$I_{(z)} = 2\pi X H_y^s(Z)\Big|_{x=t} = \frac{-I_0 t}{\pi}\int_0^\infty P(\theta) Sin\theta Z L_1(\theta t) d\theta \qquad (24)$$

This has the form

$$I_{(z)} = \left(\frac{2}{\pi}\right)^{1/2}\int_0^\infty \bar{I}(\theta) Sin\theta Z d\theta \qquad (25)$$

Where

$$\left(\frac{2}{\pi}\right)^{1/2}\bar{I}(\theta) = -I_0(t/\pi) P(\theta) L_1(\theta t) \qquad (26)$$

The total electric field in the axial direction is obtained from

$$E_z(z) = \frac{-\partial}{\partial z}(V_p + V_s) \qquad (27)$$

Applying equation (19) and (20), we obtained

$$E_z(z) = \frac{I_0}{2\pi^2\sigma}\int_0^\infty \left\{L_0\left(\theta\left[x^2 + x_0^2 - 2xx_0 Cos(y - y_0)\right]^{1/2}\right) + P(\theta) L_0(\theta x)\right\}\theta Sin\theta Z d\theta \qquad (28)$$

In particular

$$E_z(z)\Big|_{x=t} = \left(\frac{2}{\pi}\right)^{1/2}\int_0^\infty E_z(\theta)\Big|_{x=t} Sin\theta Z d\theta \qquad (29)$$

Where

$$\left(\frac{2}{\pi}\right)^{1/2}\bar{E}_z(\theta)\Big|_{x=t} = \frac{I_0\theta}{2\pi^2\sigma}\left[L_0\left\{\theta\left[t^2 + x_0^2 - 2x_0 t Cos(y - y_0)\right]^{1/2}\right\} + P(\theta) L_0(\theta t)\right]$$

$$\approx \frac{I_0\theta}{2\pi^2\sigma}\left[L_0(\theta x_0) + P(\theta) L_0(\theta t)\right] \qquad (30)$$

The impedance at the wire is

$$E_z(\theta)\Big|_{x=t} = Z_t(\theta)\bar{I}(\theta) \qquad (31)$$

Where $Z_t(\theta)$ is defined by equation (15). Applying equations (26) and (30), we can obtain the unknown $P(\theta)$ from equation (31). Thus

$$P(\theta) = -\frac{L_0(\theta x_0)\theta}{[L_0(\theta t)\theta + Z_t(\theta)2\pi\sigma t L_1(\theta t)]} \quad (32)$$

Then the desired solution is

$$V = \frac{I_0}{4\pi\sigma}\left[\frac{1}{R} + \frac{2}{\pi}\int_0^{\infty} P(\theta)L_0(\theta x)Cos\,\theta Z d\theta\right] \quad (33)$$

Furthermore from equation (33), we can say that $\theta t << 1$. Hence,

$$P(\theta) = \frac{L_0(\theta x_0)\theta^2}{[L_0(\theta t)\theta^2 + Z_t(\theta)2\pi\sigma]} \quad (34)$$

The resultant potential at (x, y, z) is valid only at zero frequency so that Z_t is the resistance per unit length of the wire.

Location

Abraka, a University town of Delta State is situated around latitude $05^o46'$ and $05^o48'$ north of the equator and longitude $06^o05'$ and $06^o08'$ east.

Experimental Work

The Schlumberger electrode configuration was used for data acquisition[14]. The ABEM Terrameter SAS 1000B with inbuilt booster was used to carry out surface resistivity measurement in the field.

The experiment was carried out in four locations with two serving as control. The main experiments are located in areas with electrical cables buried 0.5m deep in the ground. The experiment was carried out when there was electricity from Power Holding Company of Nigeria at Urhuoka, Abraka and Campus II of Delta State University, Abraka. The control experiments are areas 50m away from the source of electrical cables.

Results and Discussions

Data were collected from the various locations and the results incorporated into a computer program.

The interpretations of the VES curves were carried out in two steps. The field curves obtained from these soundings was interpreted by applying the curve matching procedure after smoothening before computer-based interpretation techniques of iteration (Egbai, and Asokhai 1998).

The computer assisted interpretation used for this work is based on the algorithm which employs digital linear filters for the fast computation of the resistivity function for a given set of layer parameters (Egbai, and Asokhai 1998).

Figure 3; cable located area shows three layers with resistivities 517,435.2 and 852.1 Ohms-meters respectively as shown in the model parameters of location 1. The thicknesses are 2.2m and 39.0m with rms (%) error of 2.1.

Fig. 3: Cable Location Area (Urhuoka)

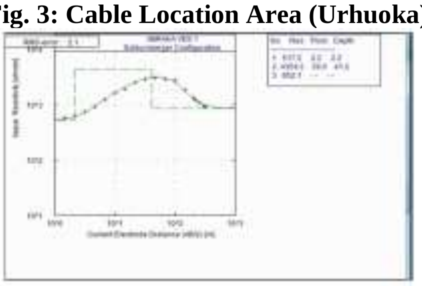


Figure 4, the control experiment has lower resistivities for the three layers as 183.3, 2764.8 and 859.6 Ohm-metres respectively. The thicknesses are 0.6m and 30.5 with rms (%) error of 2.8. The two figures (3 and 4) respectively for Urhuoka show apparent resistivity curves of k-type $(\rho_1 < \rho_2 > \rho_3)$.

Fig. 4: Control (Cable free Area Urhuoka)

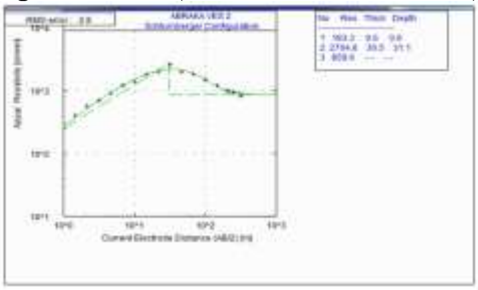


Figure 5, which are for cable located area shows 3 layers with resistivities 361.2, 6206.8 and 836.0 Ohm-metres respectively with thicknesses 1.0 and 32.5m having rms (%) error of 3.9. The curve is of k-type as shown in figure 5(Loc.3).

Fig. 5: Cable Location Area (Campus II)

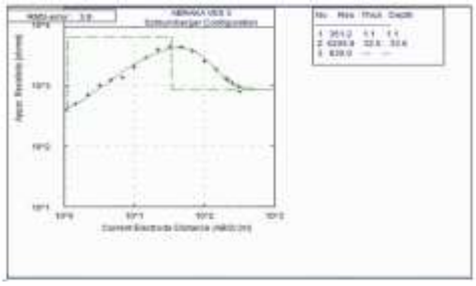
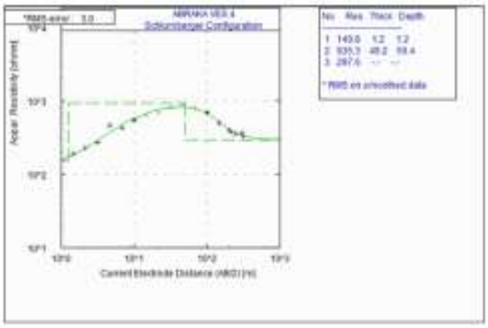


Figure 6, the control experiment of Location 4 has lower resistivities of 149.8,935 and 297.6 Ohm-meter respectively with thicknesses 1.2 and 32.5m having rms (%) error of 3.0. The curve of location 4, k-type is as shown in figure 6.

Fig. 6: Control (Cable free Area Campus II)



The pullout resistance on cables seems to increase with further increase in axial displacement Wijewickreme et al 2008). This increase in resistance with increasing axial displacement was observed in most of the axial pullout tests conducted on cables. (Ahmadnia, et al 2008) observed in their test that the overall axial stiffness of the cable to behave as a rigid body for the tested length. (Karimian H 2006) Observed that steel pipes buried in dense sand, where the peak axial soil resistance observed on buried steel pipes were noted to be several – fold (in excess of 2 times) higher than those predictions from guidelines. With direct measurement of soil stresses on pipes during full – scale testing combined with numerical modeling, (Wijewickreme et al 2008). have demonstrated that this increase is primarily due to significant increase of overall normal soil stressed on the pipelines as a result of constrained dilation of dense soil during interface shear deformations.

Conclusion

The resistivities for figures 3 and 5 are higher compared to 4 and 6. This means that the conductivities for locations 3 and 4 are lower. It shows that part of the conduction current were channel away due to the electric cable in the ground. This has resulted in higher resistivities in the two locations. The control, that is, areas without cables have lower resistivities meaning current flow is not resisted.

The experiment has show that it is not advisable to carry out VES survey when there are metal conductors such as electric cables; buried pipes etc since they can channel the current flow and distort the potential field distribution.

References

1. Ahmadnia, A; Wijeiwickreme, D; Ventura, C. E and Toth, J 2008,Response of Buried Power Transmission Cables to Earthquake – induced Permanent Ground Deformations. The 14th World Conference on Earthquake Engineering, Beijing, China.
2. ALA; Guidelines for the design of buried steel pipe. American Lifeline Alliance, 2001 Available from http://www.americanlifelinealliance.org/Products new3.htm (cited July 2007).
3. Anderson c; Wijewickreme D; Ventura C 2005,Full-Scale Laboratory Testing of soil – pipe
4. Interaction in Branched Polyethylene Pipelines, Experimental Techniques, 29:2, 33 – 37.
5. AP Pin, L. M. Berdicchevskh, G. A. Vedrintsev, G. A. Zagarmistr, A. M. Dipole,1966, Methods for Measuring Earth Resistivity (trans By G.V. Keller), Consultants Bureau, New York.
6. Egbai, J. C 1999, Noise reduction and canceling stationary sinusoidal noise in seismic data acquisition in Atala Project of River State. J. Nig. Ass. Math. Phy.vol 3 pp 208 – 221.
7. Egbai, J. C. and Asokhai 1998, Correlation between resistivity survey and well logging in Delta State; J. Nig. Ass. Math. Phy. Vol. 2 pp163-175.
8. Grant, F. S. and West, G. F. 1965,Interpretation theory in Applied Geophysics, Chap. 14, Mcgraw-Hill, New York.
9. Hill, D. A. and Wait, J. R 1979,Coupling between a dipole antenna and an infinite cable over an ideal ground plane, Radio Sci. 12 (2), 231 – 238.
10. Karimian H, 2006,Response of Buried Steel Pipelines subjected to Longitudinal and
11. Transverse Ground Movement, Ph.D Thesis, University of British Columbia
12. Keller, G. V and Frischknecht, F. C. 1966, Electrical method in geophysical prospecting. Pergamon Press, Oxford.
13. Koefoed, O. 1968,The application of the Kernel function in interpreting geoelectrical resistivity measurements. Gebrider Borntraeger, Berlin, Geoexploration Monographs series, No. 2, 108p.
14. Sunde, E. D. 1968,Earth condition effects in transmission systems. Chap. 2 (Dover Pubs., New York).
15. Wait, J. R. Hill, D. A. 1975,Propagation along a braided coaxial cable in a circular tunnel, IEEE Trans. on microwave theory and tech. MTT -23, and 401 – 405.
16. Wait, J. R. Umashankar, K. R. 1978, Analysis of the earth resistivity response of buried cable. Pageoph, Vol. 117 Birkhauser Verelag, Basel.
17. Weerasekara, L; and Wijewickreme, D,2008, "Mobilization of soil loads on buried polyethylene natural gas pipelines subject to relative axial displacements" Can. Geotech. Journal
18. Wheelon, A. D, 1968, Table of summable series and integrals involving Bessel functions, P 112 (Holden – Day, San Francisco).
19. Wijewickreme, D; Karimian, H; and Honegger D..., 2008, "Response of Buried Steel
20. Pipelines subject to Relative Axial Soil Movement". Can. Geotech Journal.