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CONSIDERATIONS REGARDING INDUCTIVE TECHNIQUES FOR KARSTIC SOIL CONDUCTIVITY MEASUREMENTS IN THE CONSTRUCTION OF ROADS, BRIDGES AND HIGHWAYS.

Tudor Burlan-Rotar [1], Constantin D. Stanescu [2], Alina Ioana Prelipceanu [3]
[1,2,3] Polytechnic University, Bucharest, ROMANIA, tudor.burlan@yahoo.com,
prof_cstanescu@yahoo.com, prelipceanu.alina@yahoo.com.

Abstract: *Karstic conditions are a prevalent problem which can impact roads, bridges and highways. the investigations are made to determine the presence of karst (sinkholes and cavities) and their possible impact on existing or new constructions.geophysical measurements are the first investigations before making a new construction. the investigations can be done in areas with historic karst but no recent activity, with sinkholes activity, or unknown karst activity. The application of electromagnetic techniques for measuring soil resistivity or conductivity has been known for a long time. . conductivity is preferable in inductive techniques, as instrumentation readings are generally directly proportional to conductivity and inversely proportional to resistivity. The operating principle of the contactless electromagnetic method is: a transmitter tx coil supplied with alternating current at a frequency audio is placed on the ground. a receiver rx coil is located a short distance s away from tx coil. the magnetic field varies in time and tx coil induces very small currents in the ground. these currents generate a secondary magnetic field hs is sensed by the rx receiver coil together with primary magnetic field hp. The ratio of the secondary field hs to the primary magnetic field hp (hs/hp) is linearly proportional to terrain conductivity. measuring this ratio, it is possible to construct a contactless, direct-reading linear terrain conductivity meter. this technique for measuring conductivity by electromagnetic induction using vlf (very low frequency), is a non-intrusive, non-destructive sampling method. the measurements can be done quickly and inexpensively. The differences in conductivity of subsurface layers of rock or soil may indicate stratified layers or voids that could be of interest.*
Key-words: *electromagnetic, conductivity, contactless.*

1. INTRODUCTION

Karstic conditions are a prevalent problem witch can impact roads, bridges and highways. The investigations are made to determine the presence of karst (sinkholes and cavities) and their possible impact on existing or new constructions.
Geophysical measurements are the first investigations before making a new construction. The investigations can be done in areas with historic karst but no recent activity, with sinkholes activity, or unknown karst activity. Using detectors devices before performing excavation, geophysical explorations made more effective.

2. ELECTROMAGNETIC METHOD FOR MEASURING SOIL RESISTIVITY

The application of electromagnetic techniques (EM) for measuring soil resistivity or conductivity is known for a long time. Conductivity is preferred in inductive techniques as instrumentation readings are generally directly proportional to the conductivity and resistivity inversely proportional.
Figure 1 presents the principle of electromagnetic method for measuring soil conductivity.

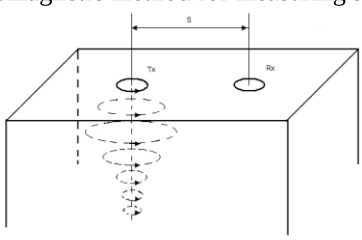

Figure 1: Principle of electromagnetic soil conductivity measurement

The operating principle of this method is:
A Tx transmitter coil supplied with alternating current at a frequency audio is placed on the ground.
A Rx receiver coil is located at a distance s from Tx coil.
The magnetic field varies in time and the Tx coil induces very small currents in the ground. These currents generate a secondary magnetic field, Hs, which is sensed by the Rx receiver coil, together, with primary magnetic field Hp.
The current induced in the coil receiver Rx is directly proportional to the conductivity of the soil:

$$\frac{H_s}{H_p} \cong \frac{i\omega\mu_0\sigma S^2}{4} \qquad (1)$$

where :

H_s = secondary magnetic field at Rx coil; μ_0 = permeability of vacuum;

H_p = primary magnetic field at Rx coil; σ = soil conductivity;

ω = 2 π f (pulsation); s = distance between coils;

f = frequency; i = $\sqrt{-1}$

Since the ratio of the secondary magnetic field and the primary magnetic field is directly proportional to the soil conductivity, can write apparent conductivity indicated by the instrument as defined by the equation:

$$\sigma_a = \frac{4}{\omega\mu_0 S^2}\left(\frac{H_s}{H_p}\right) \qquad (2)$$

The unit for conductivity is Siemens per meter or, more conveniently, milli Siemens per meter (mS / m).

3. CHARACTERISTICS OF THE DEVICE ACCORDING TO THE TYPE OF POLARIZATION

The table 1 shows the penetration depth depending on the type of polarization and the distance between the coils.

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Distance between coils (meters)	The penetration depth (meters)	
	Horizontal dipole (HD)	Vertical dipole (VD)
10	7,5	15
20	15	30
40	30	60

It can be built, for the vertical polarization, the function $\phi_V(z)$, which describes the relative contribution of the secondary magnetic field due to a thin layer at a depth z. . It is observed that the layer located at a depth of about 0.4s gives maximum contribution of secondary magnetic field, but that layer to a depth of 1.5s, yet contribute significantly.
In figure 3 is presented the function $\phi_V(z)$ for the vertical polarization.

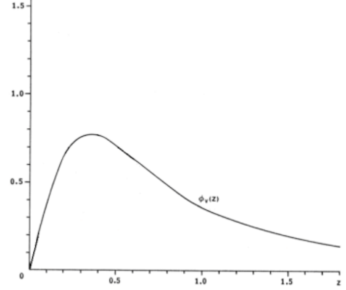

Figure 3: Operation of the device in vertical polarization mode (VD)

It is interesting to note that in the neighborhood of the surface layer has a very small contribution to the secondary magnetic field and, therefore, this configuration is insensitive to changes in conductivity near the surface.

In figure 4 is presented the function $\phi_H(z)$ for the case when the transmitter and receiver operate in the operating mode to horizontal coplanar dipoles.

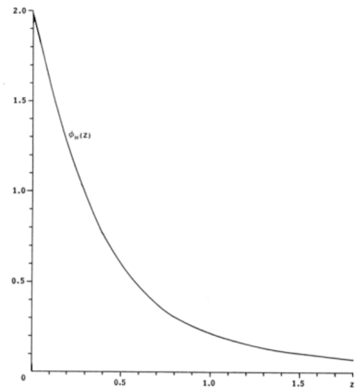

Figure 4: Operation of the device in horizontal polarization mode (HD)

The horizontal dipole orientation, the instrument is more sensitive to soil layers in the vicinity. The vertical dipole orientation device is more sensitive to the deeper layers.

Thus, by performing measurements in both modes, it is possible to measure the increase or decrease in conductivity with depth.

4. SOUNDING LAYERED EARTH

From the graphical representation of figure 3, as seen at a depth equal to twice the distance between coils (2s) signal level measured secondary magnetic field due is approximately 25% of the maximum measured.

Suppose now that semi homogeneous space has an apparent conductivity σ_a. Suppose we replace the material found below the depth 2s with a substance with infinite resistivity (conductivity zero). Thus reduced to zero contribution of 25% of the material is below the depth 2s. It follows that the remaining 75% is the value that can be measured and represents the contribution of the material is above the depth of 2s. From this example we see a simple way to calculate the value to be indicated on the instrument arbitrarily stratified earth, as long as the distance between the coils and is much smaller than any layer depth. Add the contribution of each independent layer, weighted according to its conductivity and depth.

As an example, the layered earth model with two layers.Figure 8 shows the layered earth model with two layers.

Contribution top layer is given by:

$$\sigma_a = \sigma_1 [1- R_V (z)] \qquad (3)$$

Conversely all of the material in the lower layer adds a contribution given by:

$$\sigma_a = \sigma_2 \, R_V (z) \qquad (4)$$

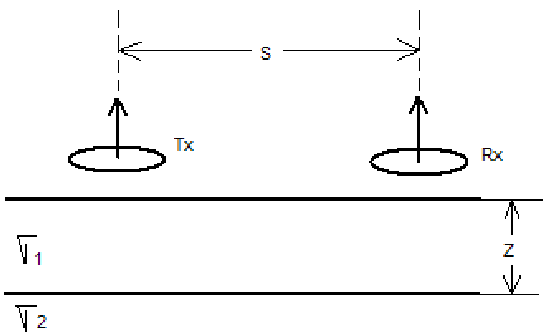

Figure 5: Model ground layered with two layers

and therefore the instrument measured value will be the sum of these two amounts:

$$\sigma_a = \sigma_1[1\text{-} R_V\,(z)] + \sigma_2\; R_V\,(z) \qquad (5)$$

If the soil has three layers using the same procedure:

$$\sigma_a \;=\; \sigma_1[1\text{-R}(z_1)] + \sigma_2\,[\text{R}(z_1) - \text{R}(z_2)] + \sigma_3\text{R}(z_2) \qquad (6)$$

In figure 6 it is shown layered earth model with three layers.

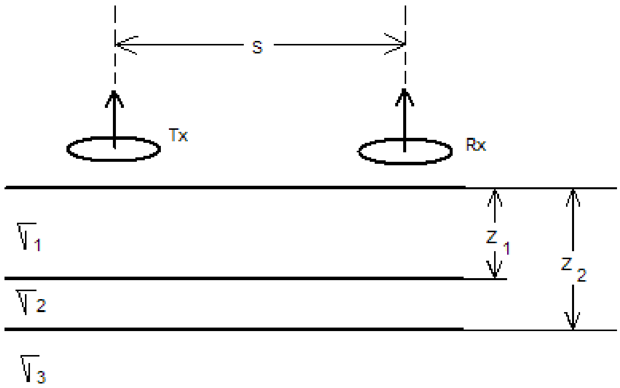

Figure 6: Layered earth model with three layers.

Ease of preparation facilitates such calculations performed survey and interpretation determinations carried out on the ground.

5. THE RESOLUTION OF A TWO-LAYER STRATIFIED EARTH

5.1. The resolution of a two-layer stratified earth by varying the distance s between the coils

This technique can be used to measure the vertical variation of conductivity is achieved by extending the distance between coils in a similar manner in which the extended distance between electrodes in conventional resistivity sounding technique.

5.2. The resolution of a two-layer stratified earth by varying heights instrument

Presented technical cannot be used when the instrument is made so that the distance between the coils has a fixed value. However, it is possible to measure the vertical variation of conductivity varying heights of the instrument.
Both sounding techniques manifests a general characteristic of electromagnetic systems , that "prefer" to look through an insulator to a conductor rather than through a conductor to an insulator.

6. KARSTIC MEASUREMENTS

The application of electromagnetic techniques for measuring soil resistivity or conductivity has been known for a long time. Conductivity is preferable in inductive techniques, as instrumentation readings are generally directly proportional to conductivity and inversely proportional to resistivity.
The operating principle of the contactless electromagnetic method is: a transmitter Tx coil supplied with alternating current at a frequency audio is placed on the ground. A receiver Rx coil is located a short distance s away from Tx coil. The magnetic field varies in time and Tx coil induces very small currents in the ground. These currents generate a secondary magnetic field Hs is sensed by the Rx receiver coil together with primary magnetic field Hp.
The ratio of the secondary field Hs to the primary magnetic field Hp (Hs/Hp) is linearly proportional to terrain conductivity. Measuring this ratio, it is possible to construct a contactless, direct-reading linear terrain conductivity meter.
This technique for measuring conductivity by electromagnetic induction using VLF (very low frequency), is a non-intrusive, non-destructive sampling method.

The differences in conductivity of subsurface layers of rock or soil may indicate stratified layers or voids that could be of interest.

The measurements can be done quickly and inexpensively.

The transmitter output current of 3A into a 100 m x 100 m loop gives good response and resolution to depths of 150 m. So it is an ideal instrument for resistivity sounding over a large area. The transmitter power supply is a 12V battery.

The transmitter current is a modified symmetrical square wave. In figure 7 are presented the transmitter current and the signal in the receiver loop.

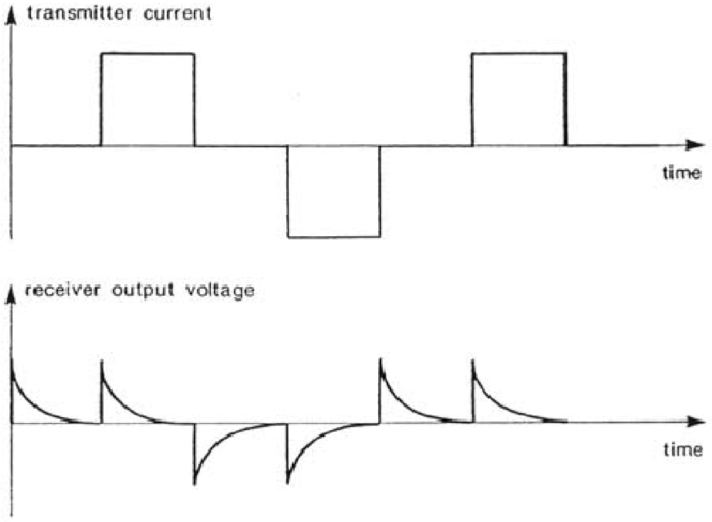

Figure 7: the transmitter current and the signal in the receiver loop.

The receiver coil is located at the middle of the transmitter loop. In figure 8 is presented the central loop sounding configuration.

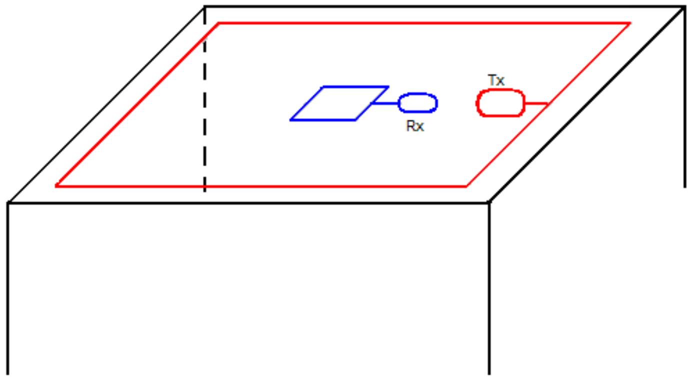

Figure 8: Central loop sounding configuration.
red: Tx - transmitter and transmitter loop,
blue: Rx - receiver and receiver loop.

The loops are air-cored for bouth: transmitter and receiver. These loops are in fact magnetic aerials. Greatest depth is obtained with large fixed loop.

7. CONCLUSIONS

The interpreted EM measurements show a distinct range of layer resistivities. The EM results can be used to map. The data points which do not fit in smoothly with neighboring points are rejected. . On the map are indicated depths separate.

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