Investigation of a Segment of Via Praetoria from Potaissa Camp by Measuring the Soil Electrical Resistivity

Mihai Munteanu[1], Levente Czumbil[1], Radu Munteanu Jr.[1], Sorin Nemeti[2]

[1]Faculty of Electric Engineering, Technical University of Cluj-Napoca, Romania
[2]Faculty of History and Philosophy, "Babeş-Bolyai" University, Cluj-Napoca, Romania

Abstract *- This paper presents the results of an electrical investigation method, carried out on a part of the Via Praetoria of the Potaissa camp. The road analyzed part was divided into two segments: the first, between the entrance to Principia and the intersection with Via Principalis and the second, between the intersection with Via Principalis and Porta Praetoria. The measurements were performed in several points, at different depths, in order to highlight the existence of the road foundation (the presence of a consistent stony material, which leads to the variation of soil resistivity values).*

Keywords – *soil electrical resistivity measurements, Via Praetoria, Potaissa Roman camp*

1. HISTORICAL CONSIDERATIONS

Due to the need to strengthen Dacia's military response force as a result of the Marcoman wars, Emperor Marcus Aurelius moved the 5th Macedonian Legion to Dacia, to *Potaissa*, a camp that will house this troop for about 100 years, until the reign of Aurelian.

The camp has an almost rectangular shape, with a fairly generous area (about 23.37 ha), which places it among the medium-sized in the Empire. The historical context in which it was built, but also the dimensions (surface) allowed very good analogies with other such military bases in the Empire: the camp of Albing (*Noricum*) has an area of 23.40 ha and sides almost as large as those of the Potaissian camp, the one in Locica (Upper Pannonia) 23.64 ha, all three being built in the context of the Marcoman wars [1-3] .

At the intersection of *Via Praetoria* (which started from *Porta Praetoria*, a gate with an eastern orientation) and *Via Principalis* (which connected *Porta Principalis Dextra* and *Porta Principalis Sinistra* and which divided the long side of the camp in a ratio of 1:1.7) the military headquarters, *Principia*, is located.

This study aims to investigate *Via Praetoria* at the points before and after the intersection with *Via Principalis*, by a method that has previously been used and which has given consistent results, the method of determining the soil resistivity [4], [5]. It should also be remembered that the *Via Praetoria* was 9.30 m wide, being built of a layer of volcanic matter (tuff), which in the area of the road axis was 20-30 cm thick (the thickness was decreasing towards the edges, where there were gutters) [1].

2. THE USED MEASUREMENT METHOD

The performed measurements on the trajectory of *Via Principalis* were based on the Wenner method, which involved (according to figure 1), the use of four electrodes: 2 current electrodes placed at the extremities and two voltage electrodes, placed centrally.

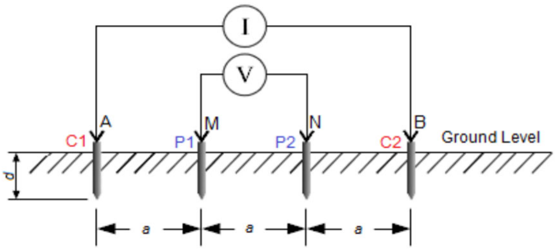

Fig. 1. Measurement scheme configuration [5]

The size of the used electrodes is *d*, being positioned at a constant distance *a* one from each other. The current injected into the ground by the electrodes placed at the extremities will produce a voltage drop measured by the median electrodes, thus obtaining the resistivity of the soil, according to the following relations [6,7,8,9]:

$$V = U_M - U_N = \frac{\rho \cdot I}{2\pi}\left[\frac{1}{AM} - \frac{1}{BM} + \frac{1}{BN} - \frac{1}{AN}\right] \quad (1)$$

$$V = \frac{\rho \cdot I}{K}, \text{ where } K = 2 \cdot \pi \cdot a \quad (2)$$

$$\rho_a(a) = 2 \cdot \pi \cdot a \cdot \frac{V}{I} \quad (3)$$

3. MEASUREMENTS RESULTS

The measurements were performed along the axis of *Via Praetoria* (the road that enters the camp's *Principia*), in 6 different points (according to figure 2); for each measurement point, 6 distinct depths were considered: 20 cm, 40 cm, 60 cm, 90 cm, 120 cm and 150 cm.

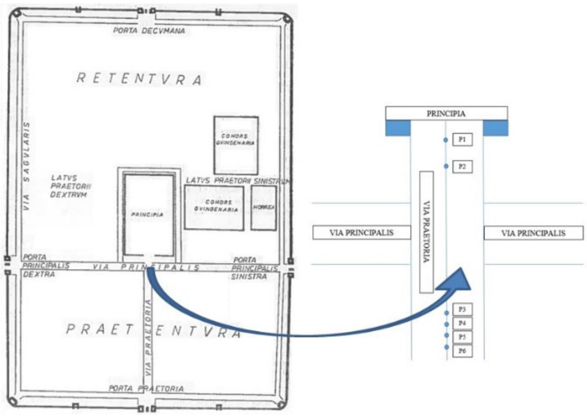

Fig. 2. Plan of the Potaissa camp [1];
placement in field of the measuring points

The location of the GPS coordinates of the 6 measuring points is as follows:

Table 1 – GPS coordinates of the measurement points

Measuring point	Latitude	Longitude
P1	46,57030	23,77314
P2	46,57031	23,77312
P3	46,57020	23,77344
P4	46,57022	23,77343
P5	46,57023	23,77347
P6	46,57020	23,77348

Also, the first two measurement points (P1 and P2) were at a distance of 2.2 m, respectively 6.2 m from the *Principia*'s entrance.

The next 4 measuring points (P3, P4, P5 and P6) were spaced 1 m apart, at a distance of 26.4 m, 27.4 m, 28.4 m, respectively 29.4 m from the entrance of the camp's *Principia*.

Consequently, the distance of 27,2 m on which the measurements were performed was divided into two segments: the first (from the entrance into the *Principia* and to the intersection with *Via Principalis*), containing the first two measuring points, and the second segment (after the intersection with *Via Principalis*), containing the following four points.

The segments where the measurements were performed are presented in the following images:

Fig. 3. The measurements area: a) for P1 and P2 points
b) for P3, P4, P5, P6 points

The results of the measurements are presented in the table below:

Table 2 – Measured values of soil electrical resistance

Depth/ Distance	Measured soil resistance [Ω·m]					
	0.2 m	**0.4 m**	**0.6 m**	**0.9 m**	**1.2 m**	**1.5 m**
2.2 m	94.2	72.1	56.8	38.1	26.09	16.89
6.2 m	66.9	59.4	38.7	23.3	13.09	7.92
26.4 m	49.2	41.6	33.7	26.11	20.28	13.89
27.4 m	47.7	37.7	33.3	23.57	17.62	12.71
28.4 m	45.6	36.4	30.3	23.43	17.37	13.42
29.4 m	43	39.8	29.56	23.03	17.41	13.62

The graphical interpretation of the resistivity values is presented below:

a) For measurement points P1 and P2:

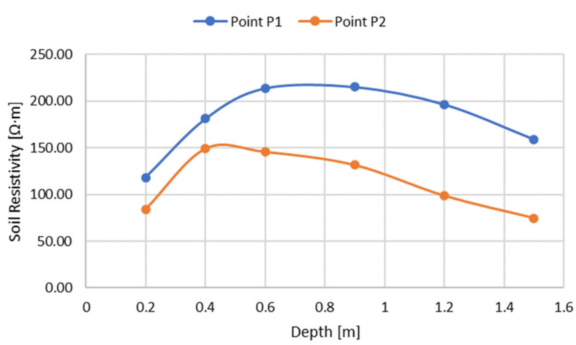

Fig. 4. The variation of soil resistivity, by depths,
at measurement points P1 and P2

It is noted that the resistivity values have an almost identical variation: in the point P1, which is placed exactly in front of the *Principia*'s entrance, the recorded maximum values correspond to depths of 60 cm and 90 cm (the difference between them is slightly over a unit), after which the values decrease.

For the point P2, the resistivity maximum values are recorded at depths of 40 cm and 60 cm (the difference is just over 3 units).

b) For measurement points P3, P4, P5 and P6:

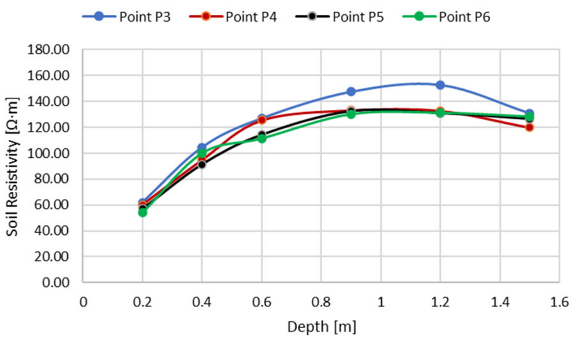

Fig. 5. The variation of soil resistivity, by depths, at measurement points P3, P4, P5 and P6

For the points P3, P4, P5 and P6, the resistivity variation curves have remarkably similar shapes: after a sharp increase and reaching the maximum values, they decrease at depths greater than 120 cm. Also, the maxima of each curve are recorded at depths values of 90 and 120 cm.

In other words, it can be concluded that at a depth of less than 120 cm there are buried stone structures, which dramatically change the values of soil resistance and thus the resistivity.

The 2D and 3D distributions of the resistivity values are presented, for the two considered segments, as follows:

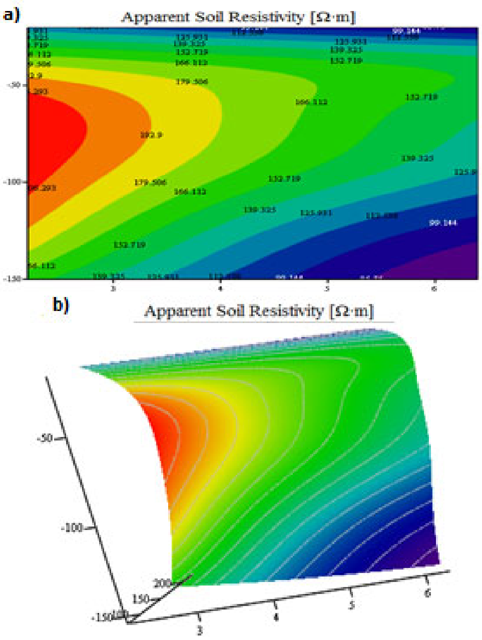

Fig. 6. Measurement points P1 and P2:
a) 2D distribution b) 3D distribution of resistivity values

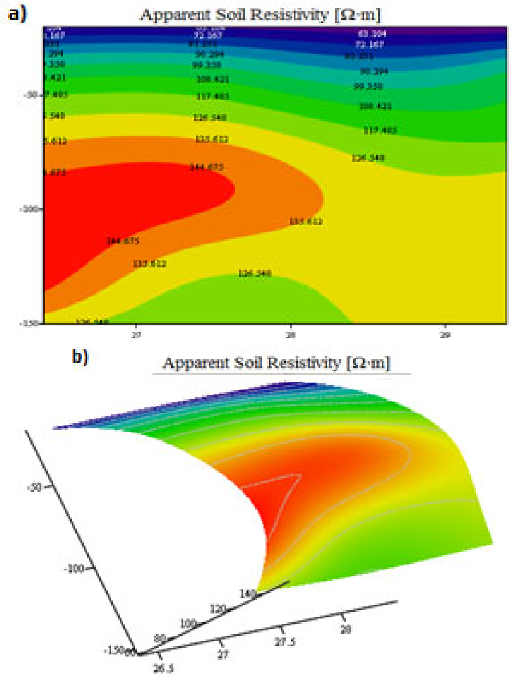

Fig. 7. Measurement points P3, P4, P5 and P6:
a) 2D distribution b) 3D distribution of resistivity values

It can be observed from figures 4 and 5 that the distribution of resistivity values in the field is remarkably similar for the two segments considered. However, it should be noted that the values obtained for the first 2 points (P1 and P2) are higher than those obtained for points P3, P4, P5 and P6 (in terms of value, the maximum for the points of the first segment is 215.45 Ω·m, compared of 152.91 Ω·m for the points in the second segment). The higher values of soil resistivity obtained in points P1 and P2, at the *Principia*'s entrance, can be determined by the existence of debris (fragments of stone blocks from the building), which over time have been buried in the ground, in front of the entry.

The images in Figures 6 and 7 can be interpreted, depending on the color code, as follows: the trajectory of the imperial road is highlighted by the red and yellow areas, i.e. by the depth regions with high soil resistivity.

For two (P1 and P5) of the six measuring points, the soil structure was determined. This is presented in the following graphs:

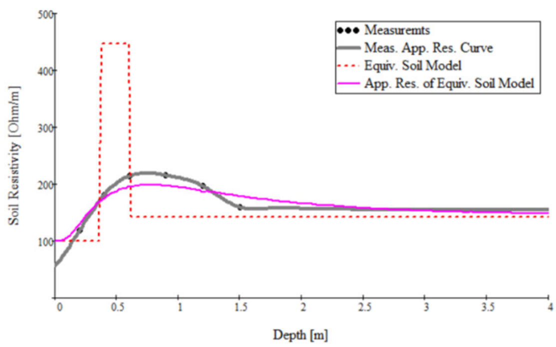

Fig. 8. Obtained soil structure for measurement point P1

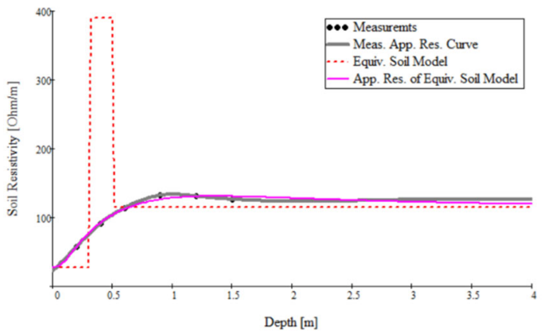

Fig. 9. Obtained soil structure for measurement point P5

With red dotted line, the soil structure is presented. Basically, there are three soil layers: the first, characterized by a low resistivity, the second with a high resistivity due to the lithic material (the stone buried in the soil) and a third layer, again characterized by a low resistivity.

4. CONCLUSIONS

The presented study proposes an electrical method for determining the buried archeological vestiges (walls, constructions), based on the measurements of soil electrical resistivity, at different depth levels.

Certainly, it was not intended to identify the route of *Via Praetoria*, since it is known from the camp plan. Instead, we aimed to probe its path (by emphasizing the existence of the lithic material from which it was built) and to compare the results with those obtained by other methods used in archaeological investigations.

Thus, the results obtained by the electrical method (variation of electrical resistivity at different depths) are consistent with magnetometry and ground radar (GPR), which were considered references[1]. Consequently, the fact that this electrical method highlights the presence of the road foundation (lithic material) validates it for archaeological research, being a solid option for identifying buried constructions.

Of course, when choosing a method used to investigate archaeological sites, the involved advantages and disadvantages must be taken into account. In this sense, determining electrical resistivity is a simple method, involving low cost equipment, but which requires high dynamics in the investigated area (continuous repositioning of electrodes).

In the future, it is intended to make measurements along the entire length of the *Via Praetoria* (from the entrance to *Principia* to the *Porta Praetoria*), in equally spaced points and at 5 different depths, in order to observe - based on the variation of soil resistivity - how the road's stone foundation was preserved.

REFERENCES

1. M. Bărbulescu, *Din istoria militară a Daciei romane*, Ed. Dacia, Cluj-Napoca, 1987.
2. M. Bărbulescu, Das Legionslager von Potaissa (Turda), Zalău, 1997.
3. C. Bărbulescu, Arhitectura militară și tehnica de construcție la romani. Castrul de la Potaissa, Ed. Napoca Star, Cluj-Napoca, Romania, 2004.
4. M.S. Munteanu, L. Czumbil, M. Pîslaru, S. Nemeti, "Electrical method for detecting buried walls min historical sites. Case study: the Potaissa legionary camp", *Acta Electrotehnica*, vol. 60, no. 3, p. 233-238, 2018.
5. M.S. Munteanu, L. Czumbil, D.D. Micu, S.F..Braicu, S. Nemeti, M. Pislaru, "Measurement of soil resistivity in order to determine the buried walls trajectory", *Advances in Electrical and Computer Engineering*, vol. 17, no. 1, p. 103-108, 2017.
6. G. Papaiz-Garbini, L. Pichon, M. Cucchiaro, "Multilayer ground determination from apparent resistivities and impact on grounding resistances", *2014 International Symposium on Electromagnetic Compatibility*, Tokyo (EMC'14/Tokyo), Tokyo, Japan, May 12-16, 2014.
7. H. Yang, J. Yuan, Y. Zong, "Determination of three-layer earth model from Wenner four-probe test data", IEEE Transaction on Magnetics, vol. 37, no. 5, pp. 3684-3687, 2001.
8. W.P. Calixto, A.P. Coimbra, J.P. Molin, A. Cardoso, L.M. Neto, "3-D Soil Stratification Methodology for Geoelectrical Prospection", *IEEE Transaction on Power Delivery*, vol. 27, no. 3, pp. 1636-1643, 2012.
9. A.C.B. Alves, R.P. Marinho, G.A.A. Brigatto, L.P. Garces, "Multilayer Stratification Earth by Kernel Function and Quasi-Newton Method", *IEEE Latin America Transactions*, vol. 14, no. 1, pp. 225-234, 2016. doi: 10.1109/TLA.2016.7430083

Mihai MUNTEANU
Faculty of Electrical Engineering, Technical University of Cluj-Napoca, 26-28, G. Barițiu str., Cluj-Napoca, Romania
Mihai.Munteanu@ethm.utcluj.ro

Levente CZUMBIL
Faculty of Electrical Engineering, Technical University of Cluj-Napoca, 26-28, G. Barițiu str., Cluj-Napoca, Romania
Levente.Czumbil@ethm.utcluj.ro

Radu MUNTEANU Jr.
Faculty of Electrical Engineering, Technical University of Cluj-Napoca, 26-28, G. Barițiu str., Cluj-Napoca, Romania
Radu.A.Munteanu@ethm.utcluj.ro

Sorin NEMETI
Faculty of History and Philosophy "Babeș-Bolyai" University, Cluj-Napoca, 1, M. Kogalniceanu str., Cluj-Napoca, Romania
SorinNemeti@yahoo.com

[1] Due to the fact that the respective researches were financed from other funds and have not been published yet, we did not obtain permission to present them in this paper.