Soil Resistivity Measurements and Investigation to Determine Underground Ancient Roman Road Right-of-Way

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Abstract *- This study highlights the results of electrical measurements (soil resistivity), performed on the trajectory of a "secondary" road, in the canabae area of the Potaissa fifth Macedonian legion camp. Although this method was mainly applied where there were large quantities of buried lithic material (stone ruins), the presented work highlights that this method is also suitable for investigating areas where gravel prevails and massive stone blocks are missing.*

Keywords *–soil electrical resistivity measurements, "secondary" road in the canabae area, Potaissa Roman camp*

1. HISTORICAL CONSIDERATIONS

The researches planned for the period 2017-2021 in the site of the *Potaissa* camp [1-3] had in view the probing and partial unveiling of the buildings identified in the *canabae* by the surveillance from 2006, when a water pipe destined to the village of Săndulești crossed the civil area of the site [4].

During the 2018 excavations, in two of the four executed squares (each measuring 5 x 5 m), on the entire surface, the north-south oriented road (cardo) was identified (which was also unveiled in 2017). From the road, the gravel infrastructure was preserved in the form of a convex lens (towards the center / the axis of the road), but also the side edges (the limits of the road), made of slabs and limestone blocks (their dimensions are variable: 55 x 30 cm, 40 x 20 cm, or 60 x 20 cm [4].

The western edge (border) of the road, made of stone slabs placed one after the other, is still preserved on a length of 5.5 m and the eastern one is almost completely destroyed by the stone plunderers of the medieval and modern era (only few slabs are preserved). The road (including the slabs) has a total width of 3.30 m and without the side edges (limestone blocks) is therefore 2.90 m, i.e. 10 *pedes* [4].

Towards the center (the axis) of the road, a convex area with a width of 1.60 m, consisting of compact gravel and limestone fragments can be observed, that may correspond to the gauge of Roman vehicles. This north-south oriented road can be identified with a cardo (or one of the *cardines*) from the *canabae* [4].

2. THE METHOD USED FOR INVESTIGATION

The investigations for detecting the trajectory of the road had as engineering substrate the Wenner method (see figure 1). One can observe that it uses two current electrodes (placed at the end of the assembly) and two central voltage electrodes, the size of the electrodes being *d*, being placed at a distance *a* from each other. The voltage drop measured by the central electrodes depends on the injected current, and thus, the ground resistivity will be calculated based on the following relationships [5, 6].

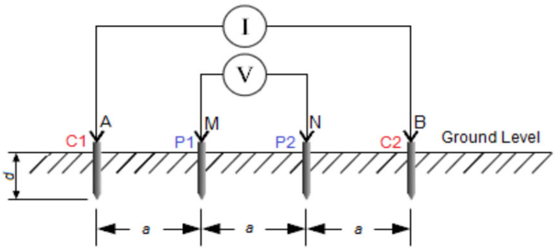

Fig. 1. Measurement scheme configuration [10]

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

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

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

It is observed that the soil resistivity at a depth *a* will be calculated according to the injected current, the measured voltage and the distance between the electrodes [7,8]:

3. RESULTS

The measurements were performed along an area known to be crossed by a Roman road: thus, east of the investigated zone, the Roman road had been uncovered by a team of archaeologists. Furthermore, it was also known that west of the investigated area, this road was intersecting another one, which was oriented on the N-S axis.

Figure 2 presents the uncovered section of the Roman road. It is noted that its boundaries (limits) were marked by relatively large stone blocks.

Fig. 2. The uncovered section of the Roman road

Following the field study, three measurement fronts were chosen: the first contained 7 points, the second 5 points, and the third 3 points. The three fronts were spaced on the E-V axis at 1 m from each other, and for each point of each working front, soil resistivity measurements were made at 4 different depths: 20 cm, 50 cm, 80 cm and 110 cm.

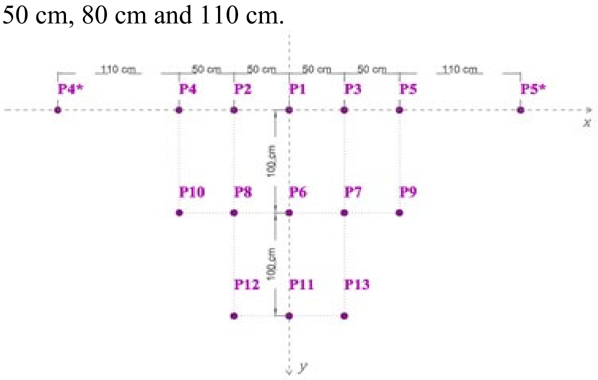

Fig. 3. Positioning of the three measurement fronts

The positioning of the three measurement fronts are presented in figure 3 and the reference (central) point P1 of the first front is defined by the following GPS coordinates: 46˚34.4401 north latitude and 23˚ 45.991 east longitude. Its placement in the field is highlighted in figure 4:

Fig. 4. Field positioning of the reference (central) point P1 of the first measurement front

The obtained results of the soil resistivity on the 3 measuring fronts are presented in the following figures:

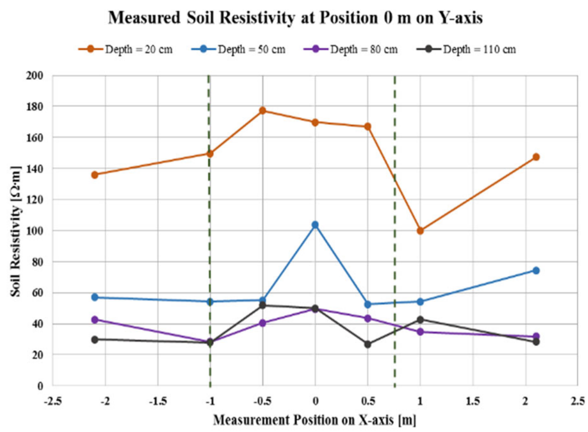

Fig. 5. Measured soil resistivity, for the points of the first measuring front, at the four depths (the presumed trajectory of the road was drawn with a dotted line)

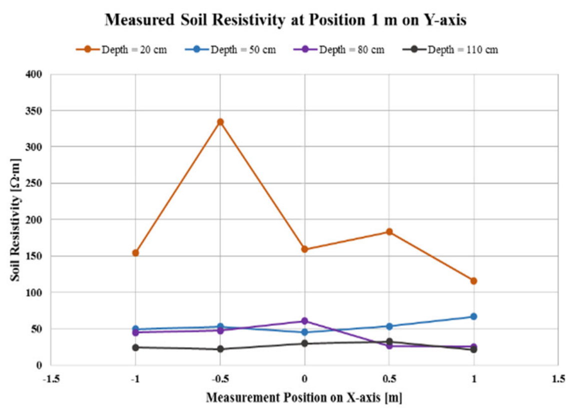

Fig. 6. Measured soil resistivity, for the points of the second measuring front, at the four depths

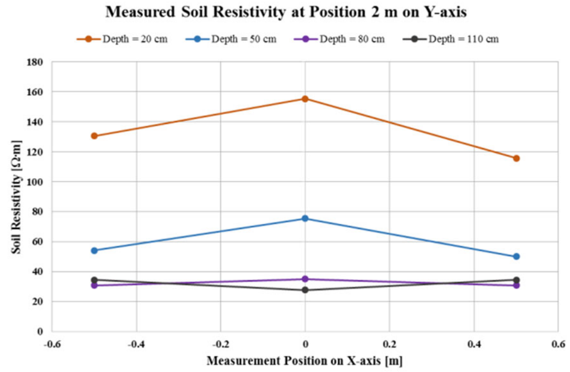

Fig. 7. Measured soil resistivity, for the points of the third measuring front, at the four depths

From the previously presented graphs (at the four depths and for all the three measuring fronts), the following observations can be made: the values of soil resistivity close to the surface (at a depth of 20 cm) are high for all points of the measuring fronts, compared to those corresponding to other depths. This could be explained by the fact that the soil was very dry, with many small pieces of stone on the surface that consequently influenced the measurements. In addition, the values of the measurements performed at depths of 50 cm, 80 cm and 110 cm are quite compactly grouped, for all the three measuring fronts.

Then, the analysis and interpretation of the results was done separately, for certain points presented in figure 3. Thus, in the P5, P7, P12 measurement points, but also in P5*, P9, P11, the following results (presented in figures 8 and 9) were obtained:

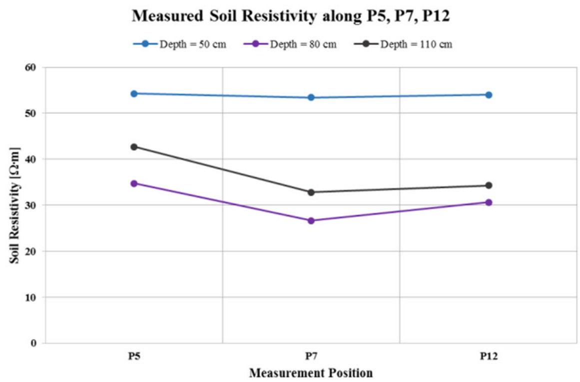

Fig. 8. Measured soil resistivity at depths of 50 cm, 80 cm and 110 cm, in the P5, P7, P12 points

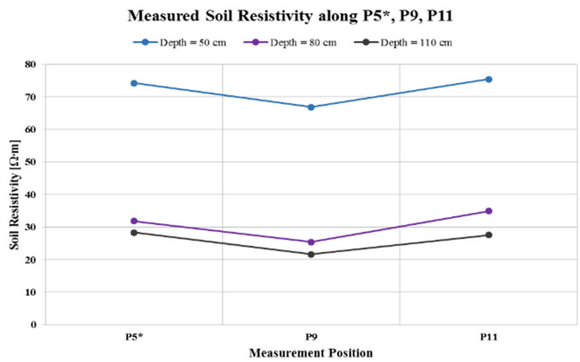

Fig. 9. Measured soil resistivity at depths of 50 cm, 80 cm and 110 cm, in the P5*, P9, P11 points

One can observe that the resistivity values are quite low, which would indicate a possible exceeding of the road limits and consequently measurements performed outside the area of interest.

The results of the measurements carried out on front 1 and front 2 of investigation, from which the values obtained at a depth of 20 cm were omitted, are presented according to the graphs in figures 10 and 11:

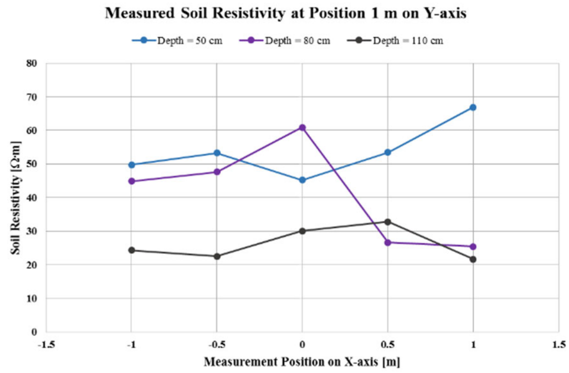

Fig. 10. Measured soil resistivity at depths of 50 cm, 80 cm and 110 cm, on the first investigation front

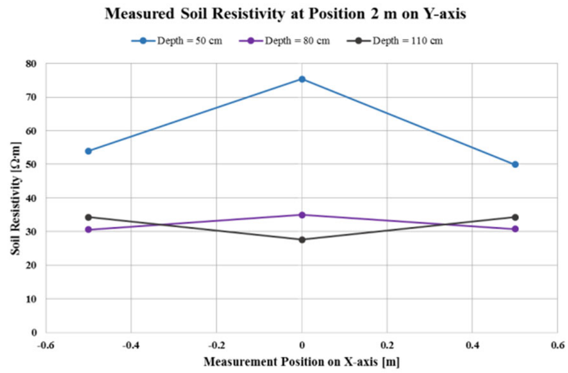

Fig. 11. Measured soil resistivity at depths of 50 cm, 80 cm and 110 cm, on the second investigation front

The results obtained for the first measuring front (y = 0 m) at the considered depths, are summarized in the 2D and 3D presentations from figure 12 and figure 13:

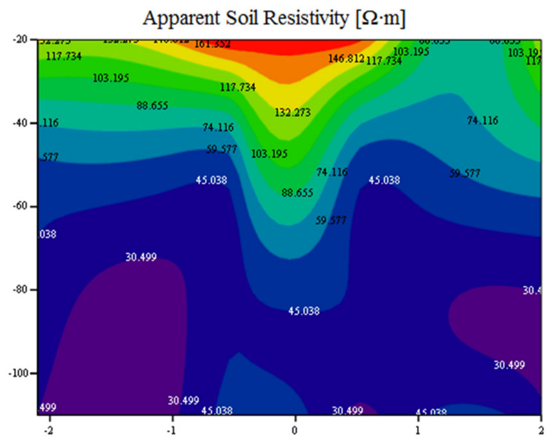

Fig. 12. 2D modeling, of the first measuring front

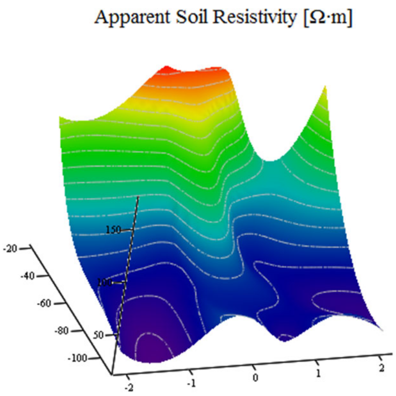

Fig. 13. 3D modeling, of the first measuring front

The results obtained for the second measuring front (y = 1 m) at the considered depths, are summarized in the 2D and 3D presentations from figure 14 and figure 15:

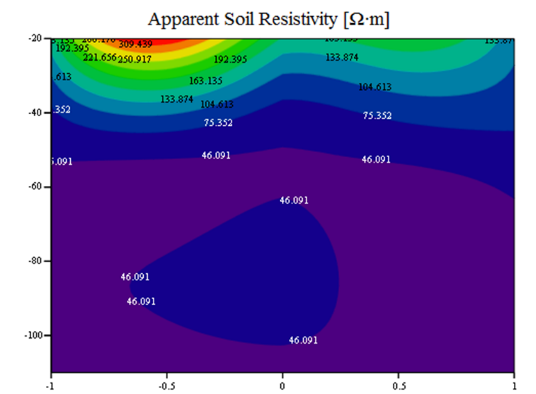

Fig. 14. 2D modeling, of the second measuring front

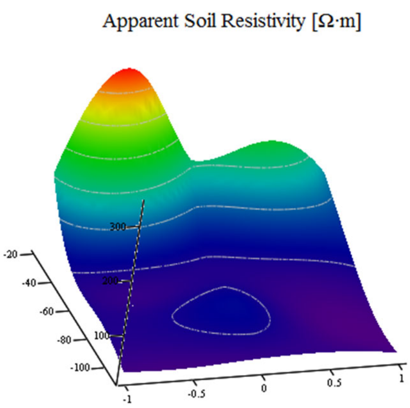

Fig. 15. 3D modeling, of the second measuring front

Based on the comparison of the results obtained at different points of the three measuring fronts (presented in Figures 5-11), the following conclusion could be drawn: some of the measuring points were chosen eccentrically to the road axis, which was due to an alignment error, enhanced by the presence of an excavated earth dump, between the uncovered area of the road and the measurement zone. In other words, starting from the numbering of the points from the three measuring fronts (figure 2), the path of the Roman road is presented according to figure 16 (b):

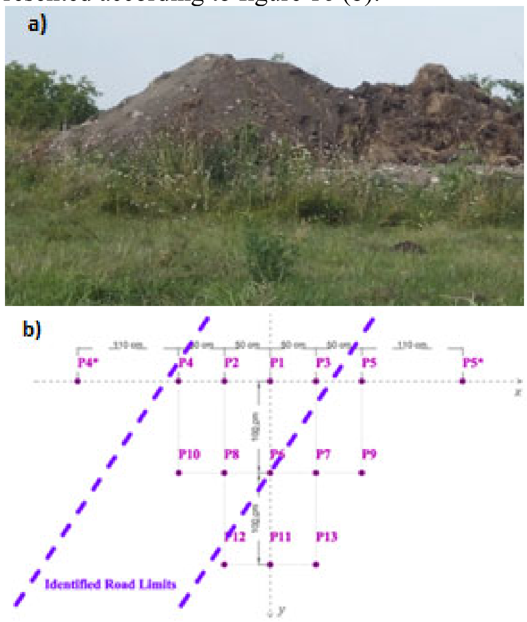

Fig. 16. **a)** Excavated earth dump, located between the uncovered area and the measurement area; **b)** The path of the Roman road and its identified limits, based on the performed measurements

4. CONCLUSIONS

Previous studies and measurements [9,10] have shown that the method of determining the soil electrical resistivity can be successfully used to determine buried constructions, or even imperial roads. If the identification of the "main" roads, which in Roman times had a consistent foundation made of lithic material, has already been proven, it was questionable whether this method can be used in the case of "secondary" roads, whose foundation mainly involves the presence of gravel (and not stone slabs of considerable size).

The interpretation of the results highlighted the fact that not all the measuring points were inside the path of the road, a situation determined by the eccentric placement of the three working (measurement) fronts, compared to the real trajectory of the road.

Thus, some measuring points are placed inside the road's trajectory (P1, P2, P3, P4, P8, P10) and others outside it (P4*, P5, P5*, P7, P9, P11, P12, P13). On the other hand, it is very likely that the P6 point to be placed above or in the immediate vicinity of the road boundary (limits), which - as can be seen in Figure 2, consisted in block stones. Consequently, the values of electrical resistivity at depths of 50 cm and 80 cm have close values, P6 being the only measuring point for which the resistivity at 80 cm increases compared to that at 50 cm. This increase in value can be given by the large stones that delimited the Roman road.

In conclusion, the measurements of soil electrical resistivity managed to identify in the field some points of the trajectory of a "secondary" Roman road, a trajectory intuited by archaeologists. Thus, the presented study proved that this electrical method can be successfully applied even for identifying this type of Roman roads, whose construction does not involve the global use of large blocks of stone.

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