GEOPHYSICS AS A TOOL IN RISK ASSESSMENT DURING ROAD CONSTRUCTION: A CASE STUDY IN A COMPLEX GEOLOGICAL REGIME IN WEST GREECE

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ABSTRACT

Road monitoring by means of visual inspection has been and will most likely remain the main procedure for many years. However, common problems such as sudden cracks and collapses of the pavement have shown that more efficient methodologies are essential. Furthermore, most of these problems are related to specific geological formations, hydrological and ground conditions that were not taken under consideration during the construction phase. During road inspection, geophysics can provide valuable insight on the possible underground extent of the observed damage and most importantly identify areas with increased probability of collapse or crack in the future. Even most importantly, near surface geophysics can be a very useful decision-making tool during construction so that these problematic areas can be mapped and future damages can be avoided.

In West Greece near the city of Agrinio, during the construction of a road, a small collapse took place near the edge of the deck of the road. Due to the presence of complex geology with thin plate limestone, karstified limestone, clay, gypsum and intense fractures related to a fault line crossing the area of interest a near surface geophysical investigation was performed in order to map possible problems along the road.

Ground Penetrating Radar (GPR) was used to scan almost 0.5 km of the road with many parallel lines and evaluation led to the classification of the parts of the road based on the condition of the soil down to 6 to 7 meters depth. According to this classification, the less safe areas were investigated further with the Electrical Resistivity Tomography (ERT) method. The ERT provided 2D and 3D images of the resistivity distribution and based on the combination of GPR and ERT results, areas with possible cavities and/or abrupt changes in the sediments or rocks were identified. The last stage was the excavation of suggested areas and verification of the results of the geophysical investigation.

Keywords: GPR, ERT, Road Inspection, Geophysics

INTRODUCTION

Construction and maintenance of the road network of West Greece is a very challenging task for all those involved due to the geological formations (rocks and sediments) that are present in the broader area but also due to the complexity with which these formation appear on the surface of the earth. Both in construction and in maintenance loose sediments, folds, cracks, faults, karstification, landslides (Diaconu and Chitea, 2018_ and several other geological conditions can be the cause of significant geotechnical problems.

Near the city of Agrinio, during the construction of a new provincial road a small collapse of the sub base was observed near the edge of the road. The road in that particular area is situated on breccia, clay, sand, folded thin bituminous limestone and gypsum from evaporates (Katsiavria, 1998). Additionally, a possible, north – south, fault line mapped in the broader area appears to cross from this part of the road (figure 1).

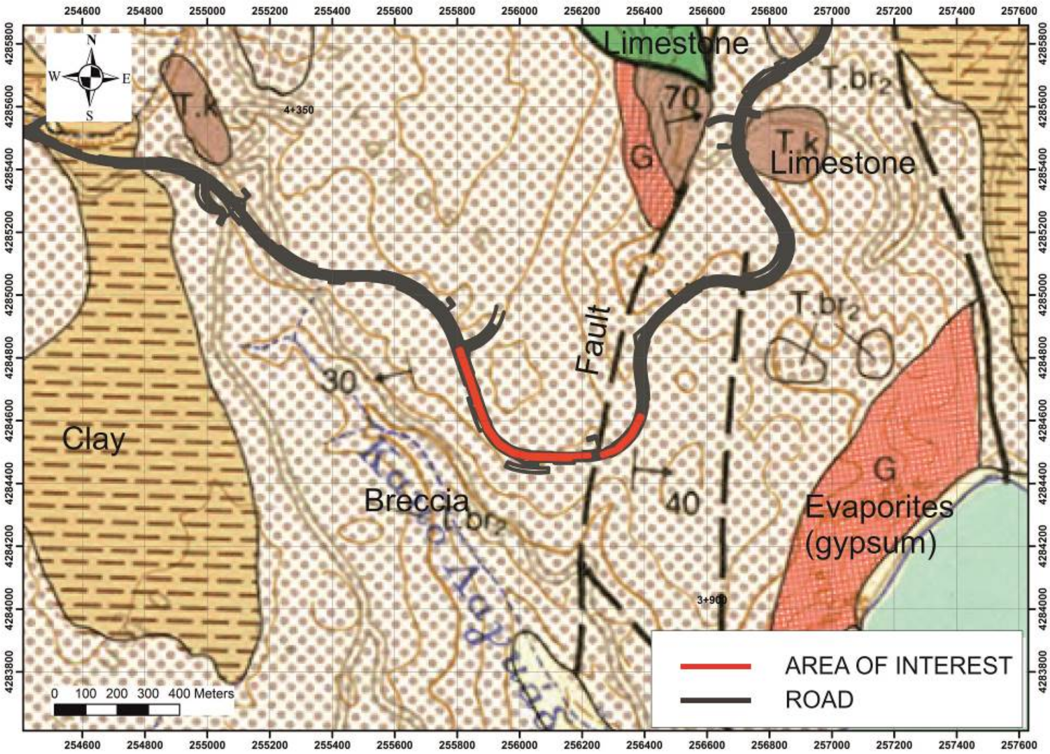


Figure 1 – Geological map of the road under construction. The red area is the part of the road under investigation. (Geological maps from I.G.M.E)

The above geological information pointed out that there is an increased possibility for more collapses or other types of damages threatening the road. We used geophysics in order to investigate almost 0.5klm of the road near to the observed collapse. The depth of investigation was approximately 7 to 9 meters from the surface.

METHODOLOGY

Usually, when geophysics is used for road maintenance, GPR stands out as one of the best, non-destructive, easy and fast method (Saarenketo and Scullion, 2000). In the case described in this paper, because the road was not paved yet, other geophysical methods were also considered and among them the electrical method and more specifically the Electrical Resistivity Tomography (ERT) method was chosen to supplement the GPR method. The ERT method is considered as one of the best methods for detecting underground cavities, but certain challenges were spotted out for certain environments (Chitea et al., 2019)

Because of the need for a three dimensional investigation of the road in a relatively short period of time we decided to proceed into two different stages namely ‘stage A’ and ‘stage B’ to complete our survey. During stage A we divided the area of interest in 12 grids (GPR-01, GPR-02, …, GPR-12) and for each grid we measured 7 parallel GPR profiles.

The profiles were placed with 1.5 meters separation and the length for each grid was selected based on the requirement that for each grid, the 7 lines would describe a perfect rectangular (figure 2). In total, we acquired little over 5500 meters of GPR data giving a complete three-dimensional understanding of the sub-base of the road and the soil beneath that. The system used was MALA ProEx and the antenna had central frequency at 250MHz. The data sampling was every 4 centimetres, which made the acquisition a little slow but provided a very good analysis in each profile.

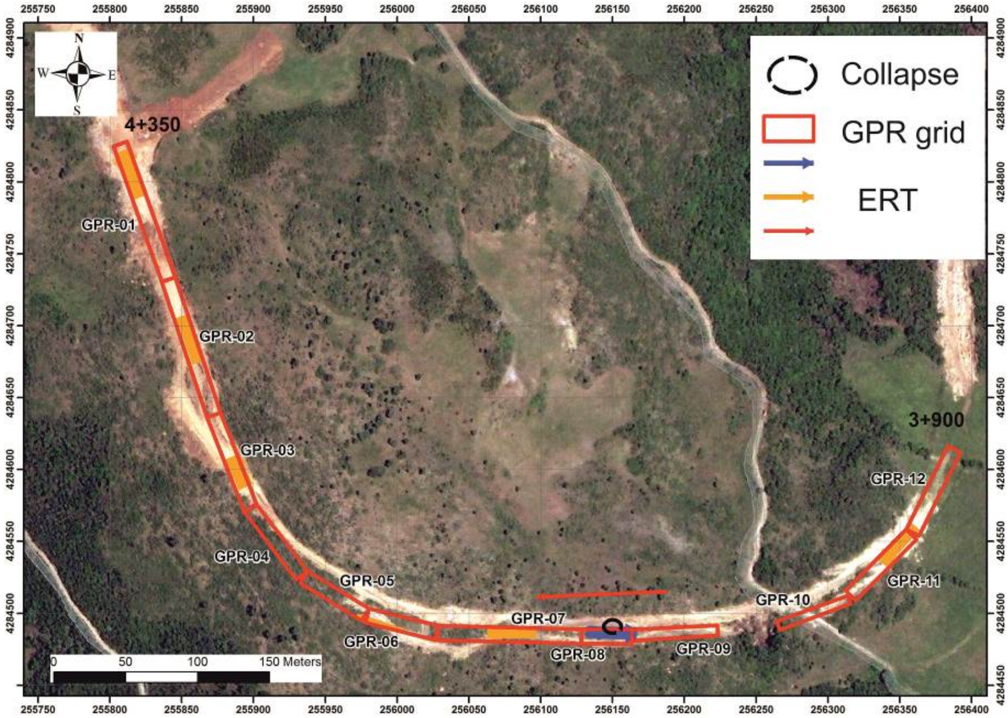


Figure 2 – Map of GPR and ERT grids of the surveyed road.

The GPR data were processed and visualised in 2D using the RADPRO software (Kim, 2005). The data were carefully inspected and edited by zero time adjustment and muting of bad traces when necessary. After a large number of tests the following processing sequence was performed: (i) calculation of representative velocity (ii) de-wow filtering (iii) custom gain (iv) filtering in wavenumber domain (v) band pass filtering in the frequency domain and (iv) median filtering in X direction. We must mention that due to the complexity of the subsurface with many different formations the calculated velocities varied significantly between 90 and 120 m/μsec but we used a mean velocity of 100 m/μsec for visualization knowing that this may change the true depth of possible points of interest even by few tenths of centimeters.

After processing the GPR data, we identified 7 areas with indications of intense irregularities in the sub-base and the soil below. We considered these areas as areas with increased probability to fail in the future and we decided to study them with a resistivity method so that we could evaluate different properties. We called this part of the survey ‘stage B’. In the areas where the GPS measurements showed significant inhomogeneity we applied also the ERT method, using 24 electrodes with separation a=1 meter or a=1.5 meters adjusted considering the length of the observed anomaly on the GPR profiles. The respective maximum depth of investigation was 7 to 9 meters and in total we measured 36 ERT profiles in 5 different locations (figure 2). We acquired the data with Syscal Pro resistivity meter by IRIS INSTRUMENTS and processed it with DC_2DPro (Kim, 2009) and DC_3DPro software (Kim and Ji, 2010).

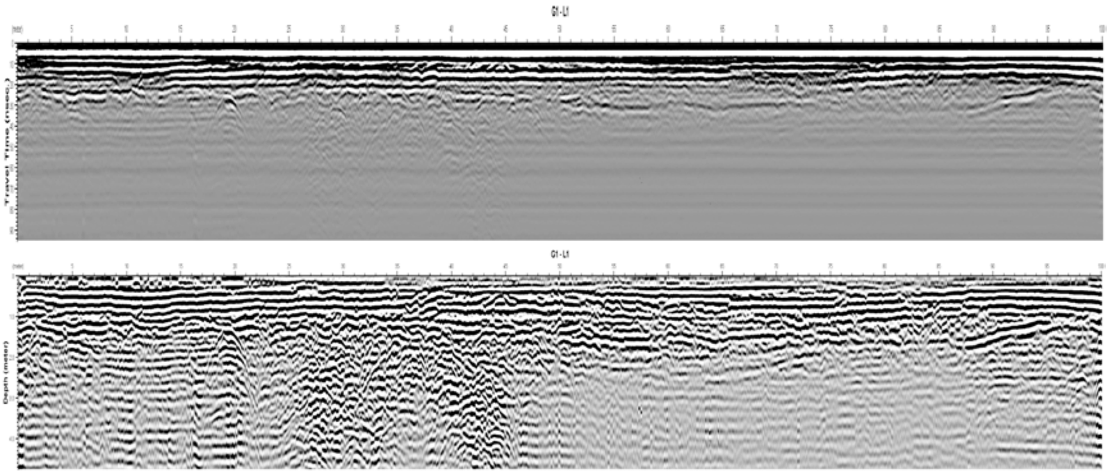
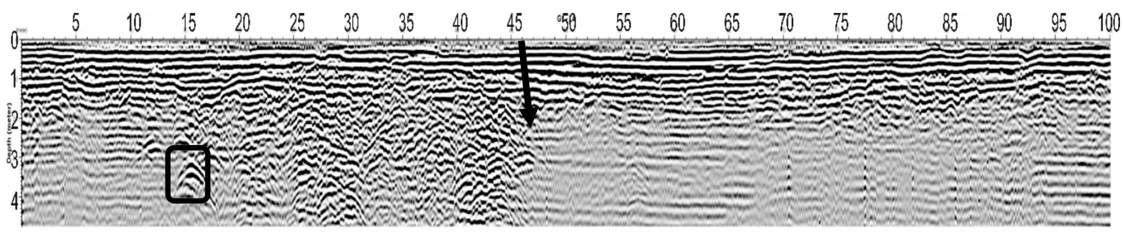


Figure 3 – Raw (up) and processed (down) GPR data from Grid1-Line1. The horizontal layering near the surface and some anomalies are pronounced strongly after the process.

RESULTS AND DISCUSSIONS

The results of the GPR survey are given in the form of 2D radargrams with the vertical axis Figure 3) transformed to depth with a velocity equal to 100 m/μsec. Based on the information given to us by the engineers we knew that in order to achieve the required topography, in some places the sub base was placed on top of the original soil, in some others the original soil was removed and finally some areas had to be filled with extra soil. As a result, different grids may present significant differences on the GPR traces for depths greater than the sub base of the road. In the following images, we present some indicative radargrams where we point out several anomalies (points\areas of interest).

In Figure 4 we present 2 radargrams from Grid1 where some strong anomalies are marked with rectangular. Furthermore, the abrupt change in the middle of both profiles are clear and persistent in all the profiles from Grid1 and can be explained by a sudden change of the geological formation. In another grid, in Figure 5, we see a very strong reflection marked in two representative radargrams from Grid 3. Most of the 70 meters long profiles reveal a rather homogeneous formation below the horizontal reflections for the sub-base.



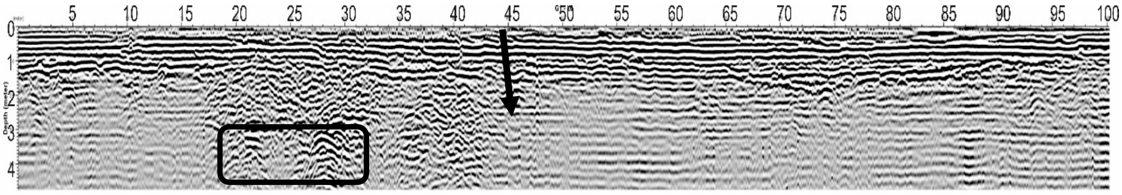


Figure 4 – GPR results from Grid1, G1-L4(up) and G1-L6(down).

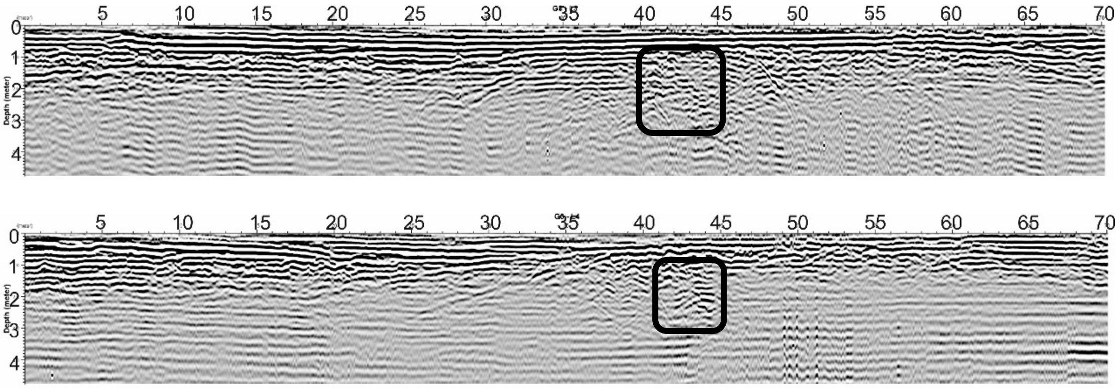


Figure 5 – GPR results from Grid3, G3-L3(up) and G3-L4(down).

The 7 areas (Figure 2) investigated by means of GPR which resulted to be suspicious for cavities or abrupt geological changes that in the future could pose a threat to the road were further investigated with the ERT survey (stage B) and the results were evaluated in comparison with the GPR results.

The case of Grid6 is the most important because it is the one that includes the area with the collapse that initiated this survey. Profiles 6 and 7 were measured crossing the small cavity that, by the day of the survey, had already been filled with clay and gravel from adjacent locations so the respective radargrams only slightly ‘recognized’ the filled cavity. However, the ERT survey in this area provided a very clear image of the formed cavity and its geometrical characteristics both in 2D and 3D results (figure 6). The ERT01 and ERT02 are measured over the cavity while the rest of the ERT lines that formed the grid were measured parallel on the road, moving away from the collapse in an attempt to investigate if the cavity continued crossing the road or not.

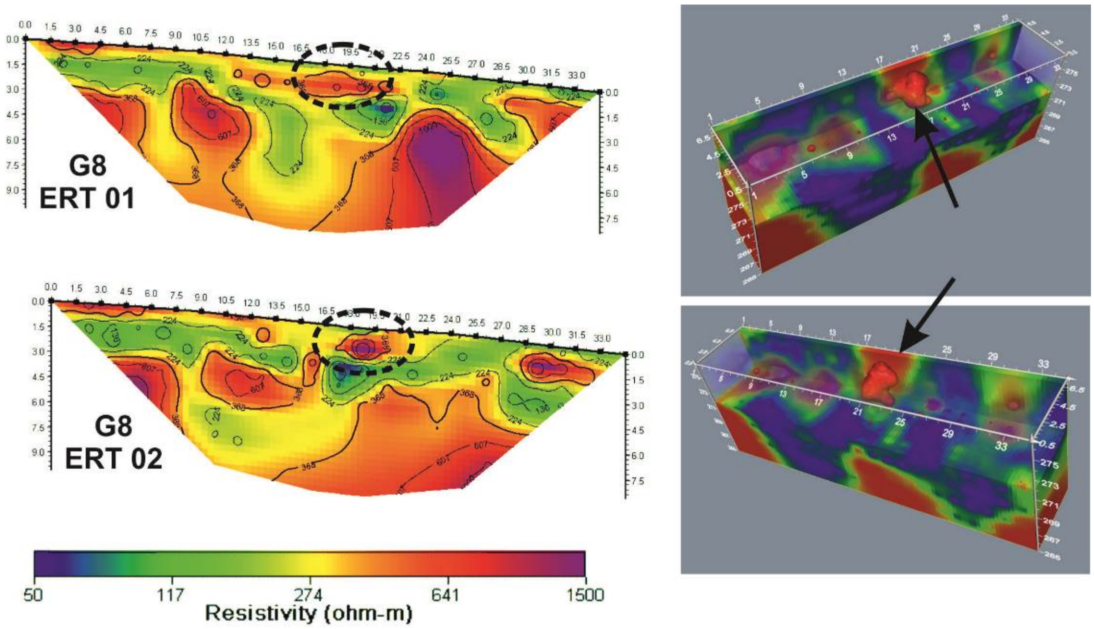


Figure 6 – ERT results from Grid8, ERT-01 and ERT-02 (left) (see text) and 3D views of the resistivities calculated in the same location (right). The high resistivity area marked with dashed lines and arrows corresponds to the cavity that caused the collapse.

Another important finding is areas with abrupt horizontal changes of formation that should be treated accordingly, to avoid future cracks in the sub base and the asphalt of the road. An example of such a case is shown in Figure 7, where the GPR results revealed a sudden change near the center of the radargram. The ERT in the same area verified this transition and based on the resistivities we came to the geological interpretation that this transition is between soft clay sediments and solid rock (limestone).

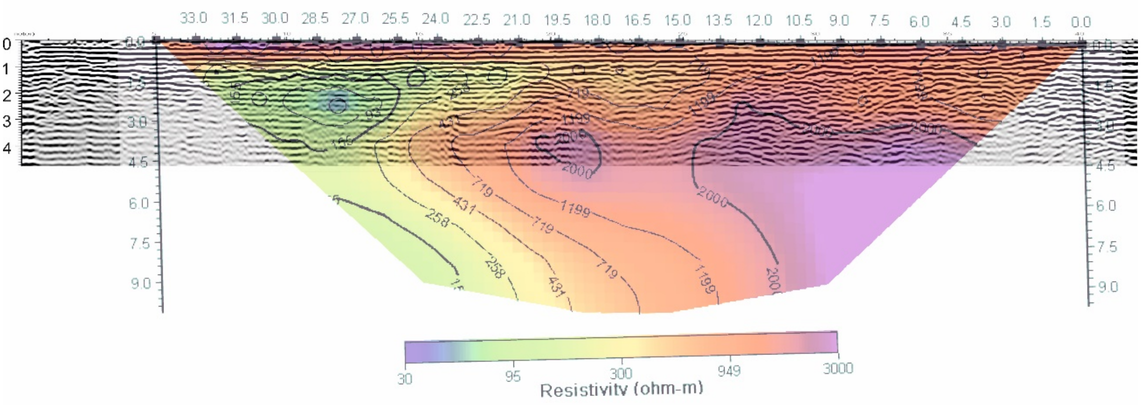


Figure 7 – Superimposed radargram GPR-L1 with ERT-01.

CONCLUSIONS

Taking into consideration all the results from the GPR survey, we marked 7 suspicious areas and comparing them with the results from the ERT survey we ended up with 3 areas that were investigated by excavation for possible cavities.

The outcome of the excavations verified the complex geology of the area that was obvious both in GPR and ERT results. However, we didn’t find any large scale cavity that can pose an immediate threat to the road construction.

Only one small cavity was identified and verified in the surveyed part of the road but this cavity revealed a possible mechanism for formation of underground cavities at small depth. In the case of grid # 7 was found a small (1* 0.80 meters) cavity that was created by the dissolution of gypsum.

As a result, was proposed that for the safety of this part of the road the surface runoff and phreatic aquifer must be considered and a drainage system must be installed.

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