GEOPHYSICAL INVESTIGATIONS AT MUNICIPAL SOLID WASTE LANDFILL JAKUŠEVAC

Stjepan Strelec, Jasmin Jug*, Davor Stanko, Mario Gazdek,
Aleksandra Anić Vučinić
University of Zagreb, Geotechnical Faculty, Hallerova aleja 7, Varaždin, Croatia

Abstract

Within the process of landfill design and defining design parameters for the construction of new, or for the old landfill remediation, long-term, expensive and relatively restricted borehole drilling is implemented. Borehole investigations give data like point with very difficult soil sampling in waste material. Deformability of waste material is crucial for the mechanical bearing resistance of the landfill. A physical-mechanical property of the landfill material depends on waste material composition, volume and density, as well as moist and landfill age that sets the rate of the total settlement.

This paper presents geophysical investigations of Municipal Solid Waste (MSW)for a detection area of intense settlement of Jakuševac landfill body. Data were generated by utilizing geophysical methods: Multichannel Analysis of Surface Waves (MASW), 2D Electrical Resistivity Tomography (ERT) and Microtremor HVSR (Horizontal-to-Vertical Spectral Ratio).MASW results help in detecting layering lithology, depth of the soil mass and elastic properties (stiffness) of waste. Geoelectrical tomography results in fine spatial profiling of the landfill body, as well as potential aquifer contamination and clay lining system detection. Microtremor HVSR is a fast and simple method to determine local site effect, or to determine the predominant frequency and amplification factor.

Anomaly determined by geophysical investigations and presented on geophysical profiles are correlated with the position of the biggest settlement visible on landfill cover system. 2D display of shear wave velocities from MASW seismic method is a direct image of deformation characteristics of the waste. Engineering-geology properties of the bedrock can also be defined from the Microtremor HVSR and ERT investigations, as well as estimation of the total volume of the waste material.

Keywords: landfill, municipal solid waste, MASW, ERT, Microtremor HVSR.

Introduction

Deformability properties of waste landfills are not easily determined since the physical composition of the mixture makes it unsuitable for the conventional laboratory deformability testing. The size of testing equipment is too small relative to the normal size of the refuse. To overcome this situation, the waste properties are established based on the type of waste, the waste processing and the placement procedures. Some properties are measured directly, such as dry density and water contents, whereas other properties, due the difficulties related to sampling, are obtained from indirect methods (borehole investigations) combining with the existent knowledge of waste properties (Sêco e Pinto, 1997). Surface-geophysical methods are quick, inexpensive and non-invasive. They help to characterize subsurface geophysical characteristics and provide information on subsurface properties, such as soil thickness and saturation, depth to bedrock, location and distribution of conductive fluids, and location and orientation of bedrock fractures, fracture zones and faults.

Borehole investigations give data like point with very difficult soil sampling in waste material. Geophysical explorations such as the seismic methods, sonic prospecting, electric prospecting, electromagnetic prospecting, gravity prospecting and radioactive prospecting can provide relatively accurate geophysical profiles without the need for drilling and sampling the landfill material (Takahashi et al.,1997).

In the winter of 2013 on the part of the municipal solid waste Jakuševac have formed the biggest settlement visible on landfill cover system. Area of the intense settlement is investigated from March 2014 to October 2014 by utilizing surface-geophysical surveys. Data were collected for three 2D geoelectrical profiles (ERT), three seismic profiles (MASW) and one profile consists of ten ambient noise measurements (Microtremors). The position of geophysical investigation profiles is shown in Figure 1.

The main purpose of this work is to use non-invasive methods to delineate the main characteristics of the area under investigation. The lack of any historical information about the uncontrolled deposition of wastes in the area requires non-invasive methods to be used to minimize the possibilities of causing further environmental damage to the site.

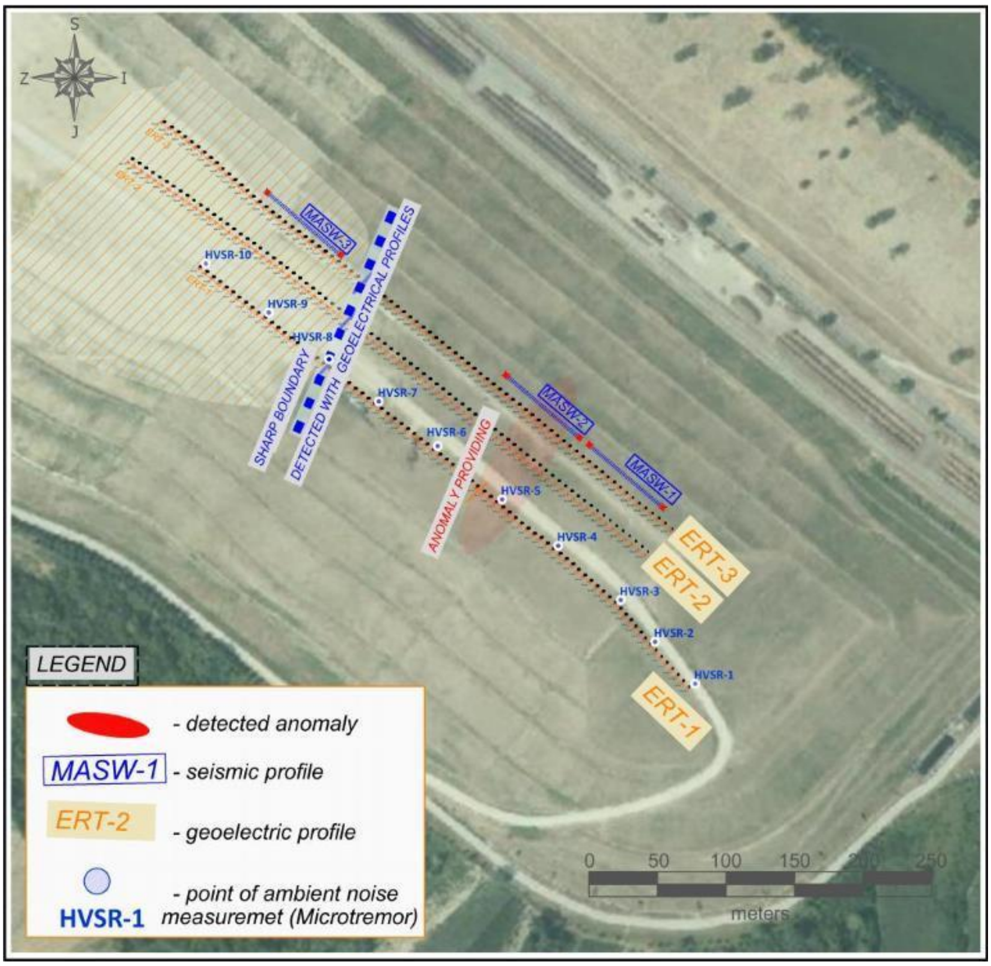

Figure 1. A ortho-photo map showing the investigated area where the geophysical measurements were carried out.

Materials and methods

Electrical resistivity tomography (ERT)

Resistivity measurements are made by passing an electrical current into the ground using a pair of electrodes and measuring the resulting potential gradient within the subsurface using a second electrode pair.Injected current and resulting voltage (potential) is measured and apparent resistivity is calculated. Apparent resistivity is a weighted average of the resistivities under the four electrodes.

Electrical resistivity tomography (ERT) or 2D resistivity imaging uses an array of electrodes connected by multicore cable to provide a linear depth profile, or pseudosection, of the variation in resistivity both along the survey line and with depth. Switching of the current and potential electrode pairs is done automatically using a switching unit with resistivity meter. The switching unit initially keeps the spacing between the electrodes fixed and moves the pairs along the line until the last electrode is reached. The spacing is then increased and the process repeated in order to provide an increased depth of investigation. A graphical display of the process is provided in Figure 2.

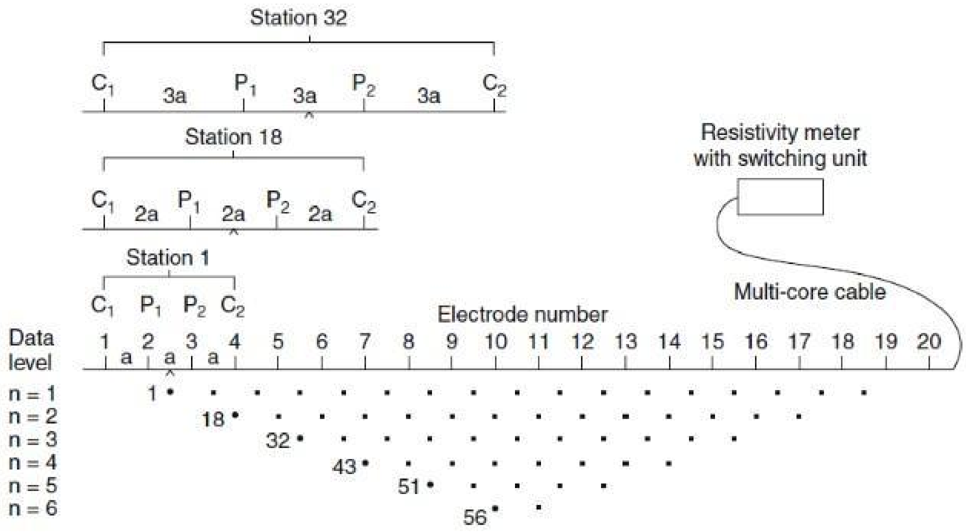

Figure 2. Schematic diagram of a multielectrode system used for 2D electric investigation and an example sequence of measurement (with 20 electrodes) used to build up a pseudosection using the Wenner array (Loke et al., 2011).

If the ground is homogenous the apparent resistivity equals the true resistivity. Interpretation software is used to invert the apparent resistivity data to true resistivity. The modelled results are displayed as scaled resistivity-depth display, where different colors according to legend showing zones of different resistivity. Results of the resistivity studies can be successfully used to map subsurface structures (e.g. shape and the total volume of the waste material) and engineering-geology properties of the bedrock at the development sites.

The Ares GF Instruments resistivity imaging system is used in this project for geoelectrical investigations. The system features 112 electrodes, enabling fully automated measurements of the shallow subsurface apparent resistivity using the Wenner array (Fig. 2). This technique has the advantage of a very good horizontal resolution. For imaging depths of about 120 m it is used electrode spacing of 5.9 m. The geoelectrical data collected have been processed by means of the RES2DINV (Loke, 1997).

Multichannel analysis of surface waves (MASW)

To characterize the dynamic properties of solid waste (shear wave velocities, Vs) on Jakuševac, multichannel analysis of surface waves (MASW) was performed. MASW, one of the seismic investigations methods, first measures seismic surface waves (Rayleigh waves, R) generated from the seismic source (sledge hammer) (see Figure 3.). Seismic surface waves are the strongest seismic waves generated that can travel much longer distance than body waves (P and S waves). The most important feature of R-waves is frequency dispersion. Waves of lower frequency (longer wavelength) spreads deeper into the medium than the high-frequency waves (short wavelengths), wherein the speed of wave propagation in a particular frequency called the phase velocity. The curve which shows phase velocity in dependence on the frequency is called the curve of phase velocity or dispersion curve. P and S waves do not have dispersive properties.

The second step (dispersion analysis) is to analyze the propagation velocities of surface waves. The occurrence of multiple phase velocity of a certain frequency is called the multi-modal dispersion. In this case, the slowest mode called basic (M0), and the next with a higher speed first higher mode (M1) and so on. The phase velocity of propagation of the Rayleigh waves (Vr) primarily depends on the speed of shear waves (Vs).

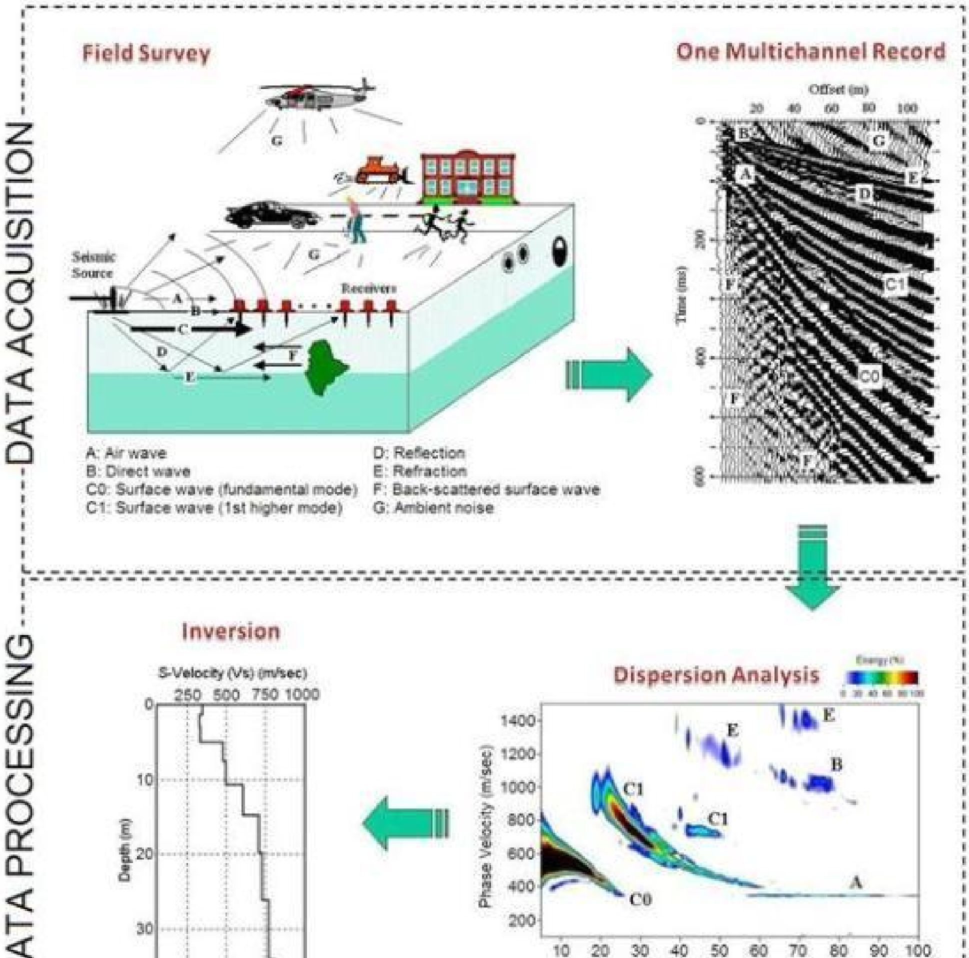

Figure 3. Common procedure for MASW surveys for 1D, 2D and 3D Vs mapping (MASW, 2005).

The inversion of surface waves (last step) is an estimation of the earth's properties from the measured surface wave data.Various types of surface wave data can be used for the estimation that may include raw field record, dispersion image, dispersion curve(s), and a preliminary 1D Vs profile or 2D Vs map (see Figures 3, 6 and 7). Regardless of the type of data used, the surface wave inversion cannot be solved directly, requiring an optimization technique to find the most probable solution in a pool of infinite candidates. This technique can be a deterministic approach, random, or combination of both.

Shear-wave velocity (Vs) variations below the surveyed area are a direct indicator of the ground strength (stiffness) and image of deformation characteristics of the waste. The maximum depth of MASW investigation that can be achieved from the survey is usually in the 10-30 m range, but this can vary with site and type of active sources used.

MASW measurements were performed with Geode Seismograph (from Geometrics). For imaging depths of about 30 m it is used 24 geophones with a spacing of 3 m. In the interpretation of MASW measurements is used fundamental or basic mode M0. The interpretation of the measured dispersion curves at the site was carried out with a PC application SeisIMAGER 4.0.1.6., OYO Corporation 2004-2009. Vs information is provided in 2D formats.

Microtremor HVSR (Horizontal-to-Vertical Spectral Ratio)

Ambient noise recordings are nowadays widely used for site response estimates, taking advantage of the fact that it is a fast, low cost, effective method. It has been extensively analyzed in the geophysical literature that using microtremors and taking the horizontal to the vertical spectral ratio (HVSR), the fundamental frequency of the sediments overlying bedrock can be estimated (Bard, 1999).

The basic principles of the method are based on one basic assumption: ambient noise consists of surface waves. Vertical motion of particles is primarily dominated by Rayleigh waves, and horizontal motion is dominated by Love and Rayleigh waves (Aki, 1957). During the past decades numerous studies, especially in Japan (Nogoshi and Igarashi, 1971; Horike, 1996), showed that by measuring ambient noise recordings and dividing the horizontal motion spectrum by the vertical one, the ratio can provide useful information regarding the resonance frequency of the location of the measurement. If the impedance contrast ratio at depth is high enough, then a distinct peak is observed at the spectral ratio, which is very close to the resonance frequency (Nakamura, 1989).

Irikura and Kawanaka (1980) report an important change in microtremor spectral characteristics when crossing a fault along a profile, proposing an explanation in terms of reflection and transmission of surface waves through a lateral discontinuity. They also proposed to use microtremor profiles as a means to detect lateral irregularities of underground structures (Bard 1999). The spectral characteristics of microtremors are changing along and across the fault zones, lateral geological borders and anomalies of the surface layers.

Microtremor measurements were performed with digital tromograph Tromino Engy (Micromed). It has 3 velocimetric channels for ambient seismic measurements (± 1.2 mm/s in the band), 3 velocimetric channels for ambient seismic vibration (± 50 mm/s in the band), 3 accelerometric channels (± 4g), 1 analog channel for trigger, integrated

GPS module and radio module for indoor and outdoor synchronization of several Tromino units. Basic data preparation and calculation of HVSR spectra are designed with computer software Grilla (Micromed). The recordings were analyzed using the HVSR method following the SESAME guidelines (SESAME, 2004).

Results and discussion

Three geoelectrical profiles were carried out which are presented in Fig. 2. From ERT is clearly visible sharp boundary between old and new cell. The older part has a much higher resistivity which indicates a significantly lower moisture content. That situation can be expected after the closing of the cell with impermeable landfill cover system, and the elapsed time of closing. On profiles ERT-1 and ERT-3 (Fig. 4) is visible a local anomaly in the field of the older cell. Anomaly is presented with a lower resistivity than the rest of the cell.

The cause of the anomaly can be assumed in the high humidity of this part of the landfill, as the result of a leakage the landfill cover system. Anomaly determined by ERT investigations are correlated with the position of the biggest settlement visible on landfill cover system (marked in Fig. 1).

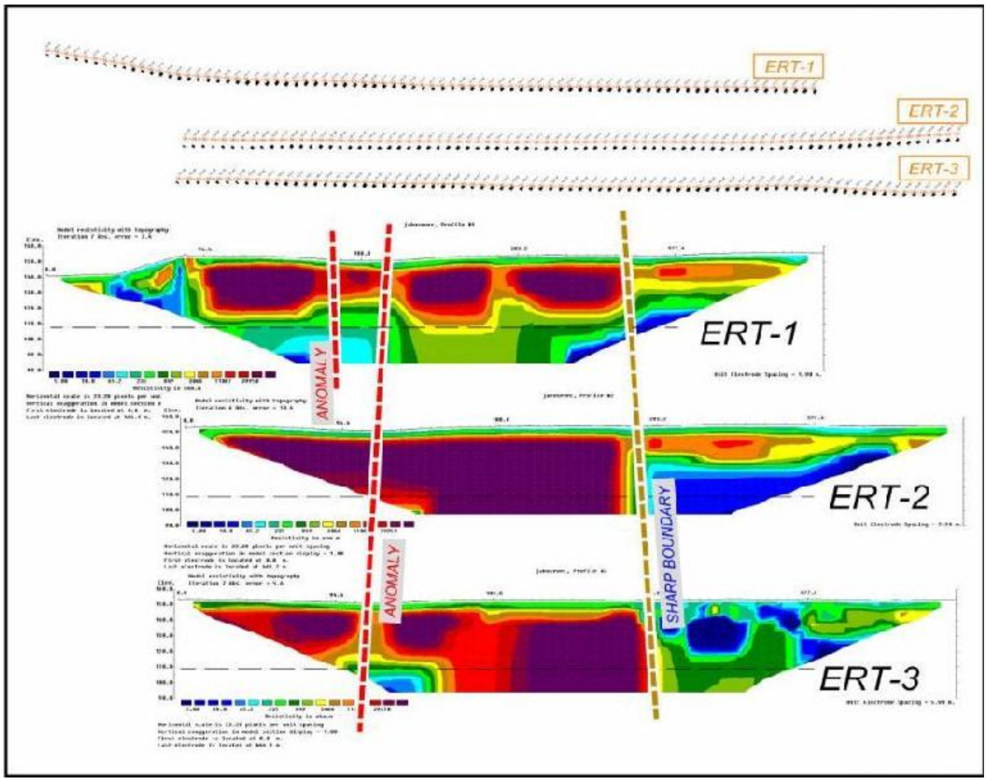

Figure 4. Inversion models of the ERT-1, ERT-2 and ERT-3 profiles.

Seismic profiles generated by using multichannel analysis of surface waves supplement the results of electrical resistivity tomography on profile ERT-3 (see Fig. 5). In the area of determined localized anomaly, the seismic profile indicates a lower speed shear seismic waves (Vs) deeper in the body of the landfill (see Fig. 6). Profile MASW-3 is recorded in the "newer" part of the landfill (see Fig. 1). Determined sudden changes in velocity of shear waves with depth on MASW- 3 (see Fig. 7) indicating that deposited waste is not consolidated.

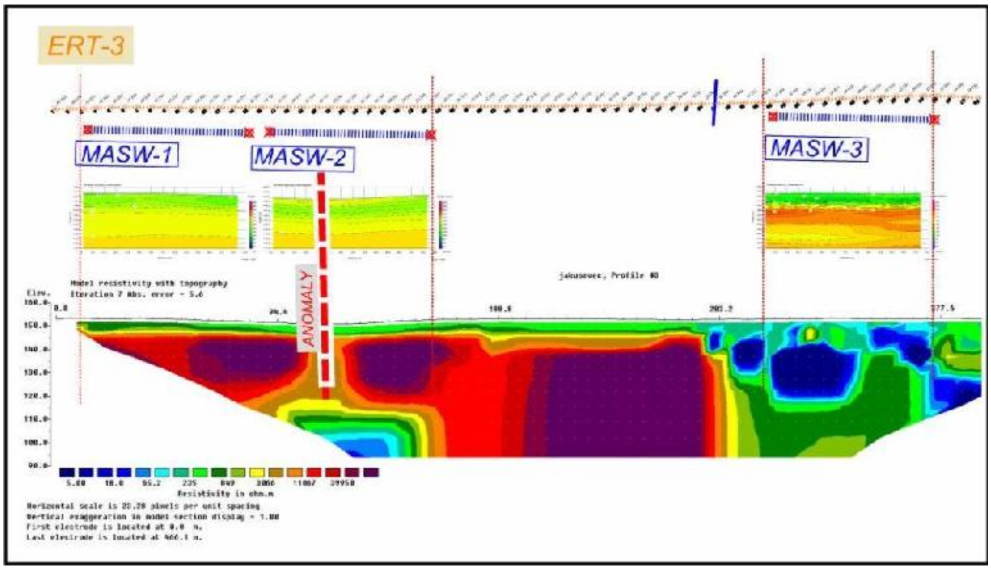

Figure 5. Validation geoelectric investigations on profile ERT-3 with MASW method.

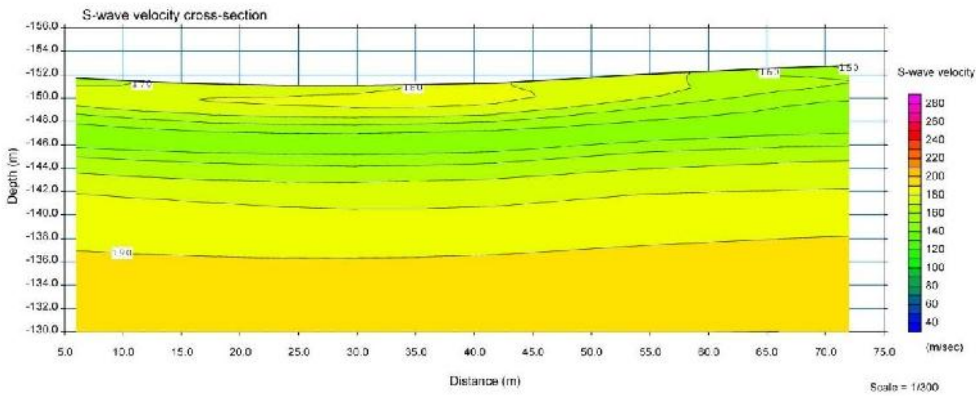

Figure 6. 2D Vs map by interpretation MASW-2 profile.

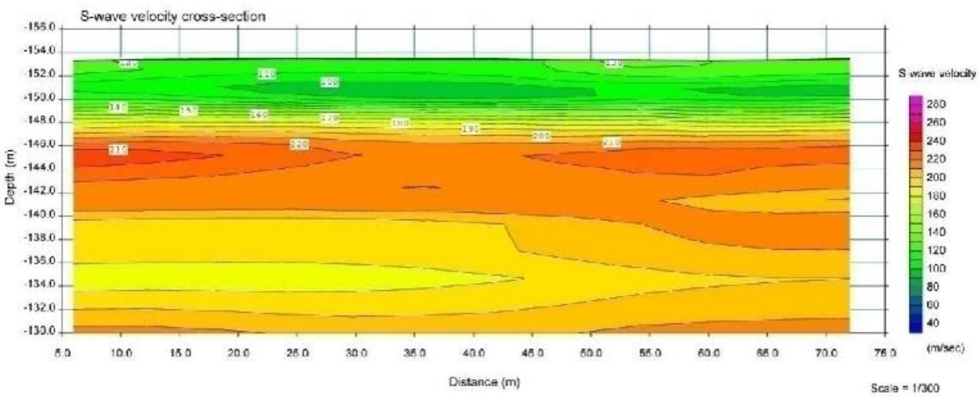

Figure 7. 2D Vs map by interpretation MASW-3 profile.

In the area under investigation, a profile consisting of ten single station ambient noise measurements was conducted. The purpose of using microtremors was: (a) to examine if HVSR can determine possible anomalies in the landfill and (b) to have a combination of geophysical methods over a possible anomaly in order to have better results. For this purpose, the microtremors profile was located at the same place where ERT-1 was conducted.

As it can be seen in Figure 8, as the HVSR profile crosses the determined localized anomaly from ERT-1, a reduction at peak frequency occurs indicating anomalies of the surface layers of landfill. The correlation of these measurements with the tomographic results of ERT-1 profile is a very good indicator that the supposed detected localized anomalies work as a resonator for the ambient noise.

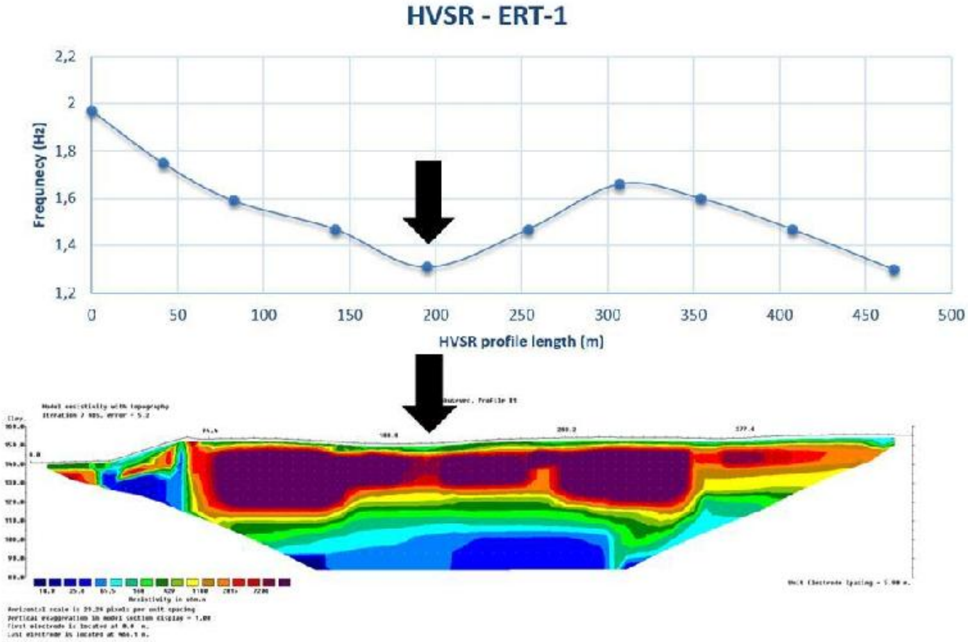

Figure 8. Frequency peaks for ten microtremor records versus distance over the tomographic results of ERT-1 profile.

Conclusion

This paper reports the results of a geophysical survey performed in the Municipal Solid Waste Site in Jakuševac (Zagreb, Croatia). The results provide evidence that the use of non-destructive geophysical methods can be applied in order to solve numerous geotechnical, geological, hydrogeological and environmental problems.

By using electric resistivity tomography (ERT) were obtained three geoelectrical profiles, on which is clearly visible sharp boundary between two cells (old and new) and a local anomaly in the field of the older cell. Geoelectrical tomography proved to be effective for profiling of the landfill body, as well as potential aquifer contamination and clay lining system detection. The results of the geoelectrical investigations were validated through the use of the seismic geophysical methods.

MASW profiles generated by using multichannel analysis of surface waves supplement the results of electrical resistivity tomography. It has been also demonstrated that the MASW could be applicable to characterize the dynamic properties of solid waste.

Shear-wave velocity (Vs) variations below the surveyed area are a direct indicator of the ground strength (stiffness) and image of deformation characteristics of the waste.

Microtremor measurements were carried out over the ERT-1 geoelectrical profile in order to obtain a better characterization of the anomaly previously detected. A good correlation between the frequency and geoelectrical anomalies emerges from the results presented. The application of ambient noise measurements in such cases could be very promising in since this method is cost-effective, non-destructive and easily applied.

References

Aki K (1957) Space and time spectra of stationary stochastic waves with special reference to microtremors. Bull Earthq Res Inst 35: 415–456.

Bard P Y (1999) Microtremor measurements: a tool for site effect estimation? In: Irikura, Kudo, Okada, Sasatani (eds). The effects of surface geology on seismic motion. Balkema, Rotterdam.

Horike M (1996) Geophysical exploration using microtremor measurements. Xth World conference earthquake engineering, Acapulco, #2033, Elsevier Science Ltd.

Irikura K, Kawanaka T (1980) Characteristics of microtremors on ground with discontinuous underground structure. Bull Disaster Prev Inst Kyoto Univ. 30: 81–96.

Loke M H (1997) Rapid 2D resistivity inversion using the least-squares method. RES2DINV program manual, Penang, Malaysia.

Loke, M.H., Chambers J.E. and Kuras O. (2011) Instrumentation, electrical resistivity In Solid Earth Geophysics Encyclopedia (2nd Edition), Electrical & Electromagnetic, Gupta, Harsh (ed), pp. 599–604, Berlin, Germany: Springer.

MASW (2005) Guidelines for the implementation of the multichannel analysis of surface waves: data acquisition and data processing.

http://www.masw.com/OverallProcedure.html (acessed April 10, 2016).

Nakamura Y (1989) A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. QR Railway Tech Res Inst 30: 25–33.

Nogoshi M, Igarashi T (1971) On the amplitude characteristics of microtremor (Part 2). J Seismol Soc Jpn 24:26–40.

Sêco e Pinto, P S (1997) Analysis of the behaviour of solid waste landfills (in portuguese). Seminar on Geoenvironmental Aspects of Industrial Solid Waste Landfills, Lisboa.

SESAME (2004) Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations: measurements, processing and interpretation.

http://sesame-fp5.obs.ujf-grenoble.fr/Delivrables/Del-D23HV_User_Guidelines.pdf (acessed March 18, 2016).

Takahashi T, Mimoto K & Hayakawa T (1997) Present state of applications of geophysical methods to characterization of active faults. Journal of Japan Society of Engineering Geology 38: 118-129.