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Investigation of waste disposal areas using electrical methods: a case study from Chania, Crete, Greece

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Abstract A geophysical investigation of a landfill area was conducted as an inextricable phase of a preliminary geotechnical, geological and hydrogeological study of the area under investigation. Electrical resistivity tomography (ERT), one of the most promising prospecting techniques mainly concerning its effective contribution to resolve several environmental problems, was applied for the geophysical modeling. ERT is a robust imaging method of the theory and implementation of which are well documented in geophysical research literature. The survey site is located in Akrotirion Peninsula, about 7 km east of Chania city in Crete I. The geological setting comprises Trypalion limestones, marly limestones and a clayed weathered layer. Cavities are also identified at various scales which are recent tectono-karstic voids. Due to the above-mentioned geological singularity and in the light of the requirement for an environmentally safe construction of the landfill, an ERT survey was

carried out. Specifically, seven geoelectrical tomographies were conducted reaching the prospecting depth of 36 m. The resulted images conducted, to overcome geotechnical problems since the spatial distribution of karstic voids was determined, to plan the future sites for waste disposal as the geological conditions were studied in detail and to reliably estimate the thickness of the already deposited wastes. The resulted images were confirmed using available borehole logs and ambient noise measurements.

Keywords Electrical tomography · Landfills · Environmental geophysics · Cave detection

Introduction

Nowadays, the problem of environmental contamination and waste management is one of the main concerns of earth scientists and researchers from other related fields of science around the globe. Fast industrial development and the uncontrolled growth of the urban

population result in the production of toxic solid residues. Urban waste materials, mainly domestic garbage, are usually disposed of inadequately in waste disposal sites posing a high risk to the underground water resources, the environmental pollution and the community health. Moreover, older waste sites often lack reliable geological or artificial barriers, so that

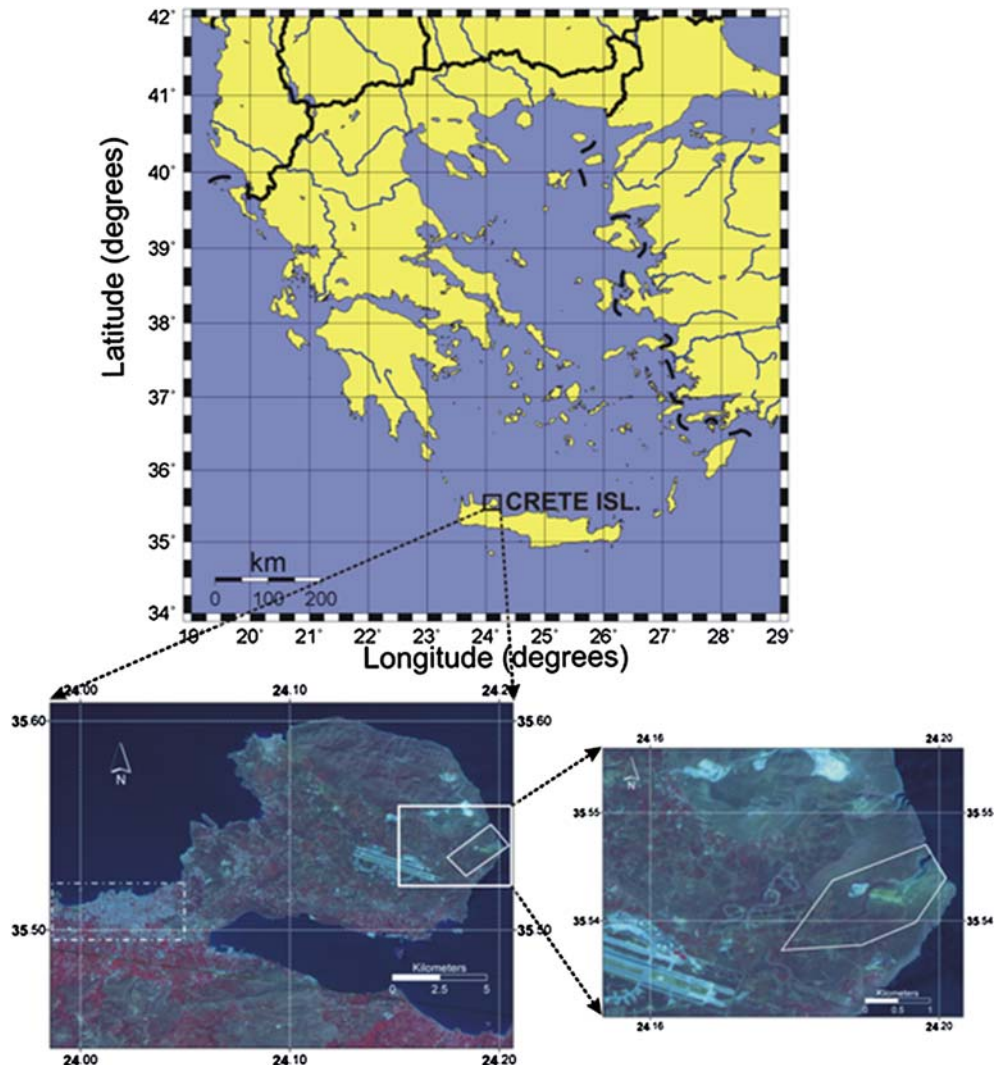
leaching of pollutants into the groundwater is a concern. Contamination problems are particularly severe for waste dumped in abandoned gravel pits, many of which extend to below the groundwater table. Being small-sited and unregulated, the exact location, structure and contents of such landfills are either unknown or poorly documented.

The solution to the day-to-day problems of modern urban societies demands fast and effective geophysical methods. One of the most frequent demands in metropolitan areas is to determine the landfill's geological and geotechnical structure shape and extend, together with the excavation and dumping history (Allen et al. 1997; Bagchi 1994; EPA 1995, 1996, 1997, 1999a, b; DELG 1998, 1999; Hillary and Samuel 1993; Langer 1995; Mather 1995; Georgaki et al. 2006). Details on the contents of a landfill may be difficult to acquire but are essential for evaluating the level of risk associated with

leaking pollutants. In such context, the integrated use of geophysical methods provides an important tool in the evaluation and characterization of contaminants generated by urban residues (domestic and/or industrial) (Beres and Haeni 1991; Davis and Annan 1989; Green et al. 1999; Heitfeld and Heitfeld 1997; Lanz et al. 1994; Orlando and Marchesi 2001; Soupios et al. 2005a, b, c; Saltas et al. 2005). Among those geophysical methods, electrical methods have been found very suitable for such kind of environmental studies, due to the conductive nature of most contaminants. The use of electrical methods applied to environmental studies is well documented (Atekwana et al. 2000; Sauck 2000; Sauck et al. 1998; Stanton and Schrader 2001; Karlik and Kaya 2001; Bernstone et al. 2000; Aristodemou and Thomas-Betts 2000; Dawson et al. 2002).

To evaluate the capabilities and limitations of geophysical methods in providing accurate information on

Fig. 1 3,2,1 (R,G,B) color composite of the three VNIR bands of ASTER satellite image showing the city of Chania (white dashed rectangle) and the Akrotirion Peninsula as well as a detail of the study area. White solid rectangles indicate the Kouroupitos gorge



typical small waste sites and their host sediments, we have conducted a variety of surveys over and around a composite landfill in Akrotiri Peninsula in Chania as a case study (Fig. 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.

Specifically, the focus of this survey was primarily of a qualitative nature and the main objectives were to determine: (a) if electrical resistivity tomography (ERT) could be used to map near-surface cavities (less than 30 m in depth) in a limestones karstic area such as Akrotirion Peninsula which caused serious geotechnical and construction problems, (b) the geological, hydro-geological and geotechnical applicability of new proposed areas for waste deposits and (c) the accurate characteristics of the deposited waste in the gorge in order to design a potential rehabilitation and decontamination program since the information collected in this investigation may be useful to optimize subsequent sampling and remediation.

Geology of the study area

The area under investigation is located in the Akrotirion Peninsula, 12 km east of the city of Chania (Fig. 1), in the Kouroupitos gorge which has a length of 800 m and a maximum depth of 40 m (Fig. 1). The broader area of Akrotirion Peninsula consists mainly of two sub-areas (Fig. 2). The northern area is composed mainly of karst

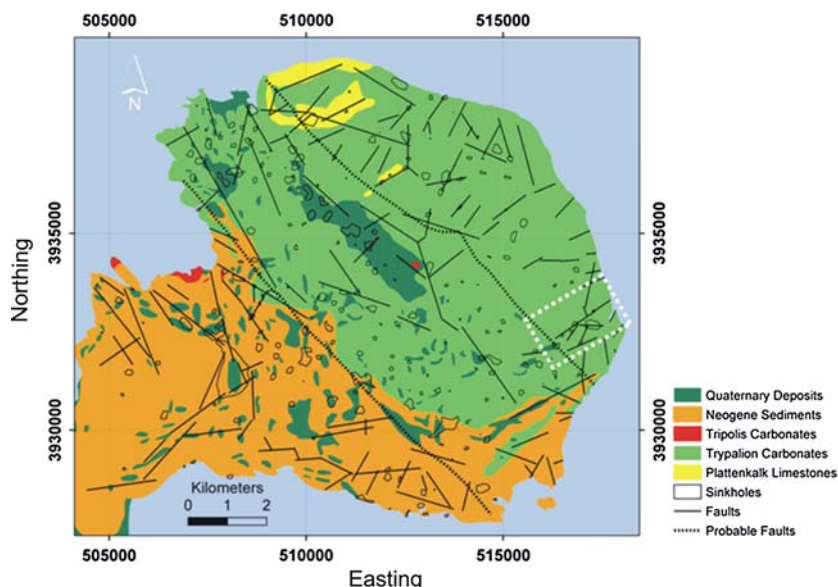
water-bearing carbonate rocks (limestones, marly limestones and a clayed weathered layer) of Late Triassic to Early Jurassic age (Trypalion carbonates) overlying Permian Plattenkalk Limestones. The Southern–Western part consists of Neogene sediments while Quaternary deposits cover several places in the Akrotirion Peninsula (Fig. 2).

Both sub-areas and especially the northern one, are characterized by abundant karst depressions (sinkholes) such as dolines and uvallas (Fig. 2) interpreted as the result of karstic erosion combined with the tectonic stress on the Trypalion limestones. The sinkholes in Fig. 2 were extracted subtracting the digital elevation model (DEM) of the study area with a cell size of 30 m, from the combined geological/hydrological corrected DEM (Figs. 2, 3) with the same cell size. Many of the extracted tectono-karstic voids correspond well with the previously observed cavities while their existence was further confirmed during the field observation (Fig. 3).

Many different tectonic movements have affected the exposed rocks. The major WNW–ESE direction (Fig. 2) mainly represents limestone bedding and is responsible for the formation of the karstic structures (Fig. 3). The photo-lineaments extracted from the on-screen interpretation of the panchromatic band of the Landsat-ETM satellite image of the study area with a spatial resolution of 15 m, are of a NW–SE and a NE–SW direction (Fig. 2), inferring the presence of a well developed joint system in the area.

The stream network of the study area is entered into autochthonous alpine marly and dolomitic limestone and its pattern is closely related to the tectonic structures, while the area is in a mature stage as far as the fluvial erosion cycle is concerned. The aquifer is mainly

Fig. 2 Geological map of the Akrotirion Peninsula with the photo-lineaments interpreted as faults overlay. The digital elevation model extracted depressions interpreted as sinkholes are also overlain. The location of Kouroupitos gorge is shown with *dashed white rectangle*



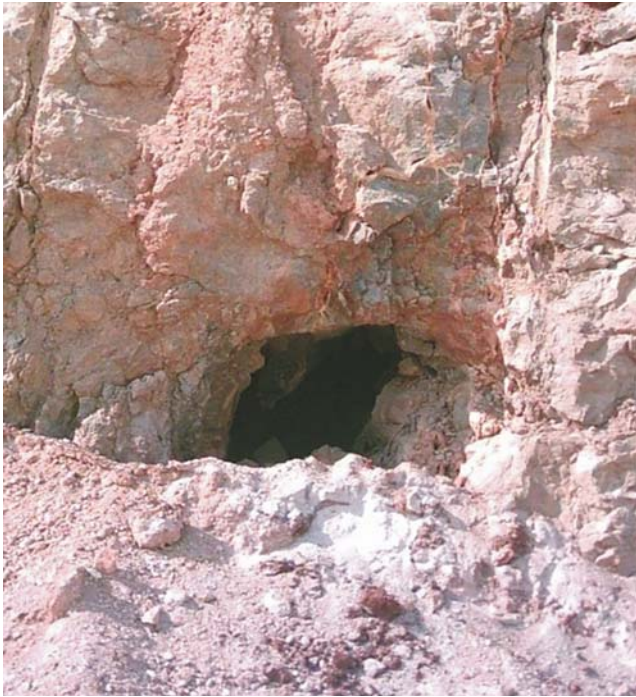


Fig. 3 Karstic void exposed during the excavation for the foundations of the main building prospected, 20 m away from the starting point of ERT1

expected to be inside the fractures developed in the limestone and the free underground water level is located 31–35 m below the surface. The pore water pressure is hydrostatic from this level.

Geophysical exploration

Surface-geophysical methods offer quick, inexpensive and non-invasive means to help characterize subsurface geophysical characteristics. They 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.

However, there are numerous limitations to the information obtained by the geophysical techniques and they shall not be expected to provide reliable results under all circumstances. All geophysical information should be cross-checked by borings and/or other direct methods of exploration.

Surface-geophysical surveys were conducted in the municipal waste disposal site in Chania in Crete Island, from May 2004 to October 2004. Data were collected for seven 2D geoelectrical profiles (ERT) and one profile consists of eight ambient noise measurements (Microtremors).

Electrical resistivity survey

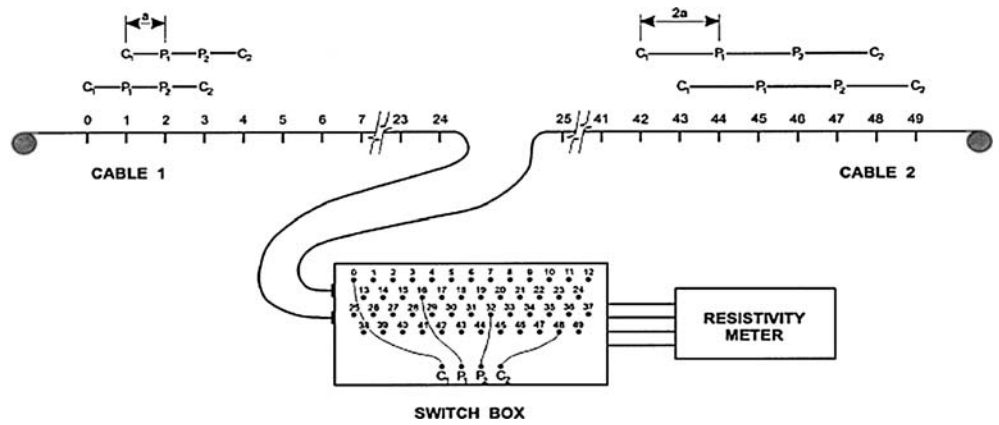
In many cases the ground cannot sensibly be resolved into plane homogeneous layers, as required for Vertical Electrical Sounding work, or into simple zones of lateral conductivity variation as required for profile interpretation. A combination of the two techniques is required. Electrical resistivity imaging (Griffiths and Barker 1993; Loke 1999; Acworth 1999) is one approach to this problem. Electrical images can be measured in two dimensions with the assumption that little variation exists in bulk material values in the third (normally the y) dimension or in three dimensions. Two-dimensional work is routine and the field and interpretation procedures have been developed to the extent that the process is now almost as rapid as for 1D sounding investigation. Three-dimensional surveys are not yet routinely carried out as they require correspondingly larger amounts of field equipment and the interpretation times for the large data sets acquired are still considerable.

For imaging depths of about 30 m it is convenient to use electrode spacings of 5–10 m, depending on the subsurface resistivity. Two current (C1, C2) and two potential (P1, P2) electrodes, are each connected to a take-out on the multicore cable and the cable is connected to a switching box which is manually controlled, or to a switching module which is computer controlled. Typical cables have between 20 and 25 take-outs with 2, 5 or 10 m separation between each take-out (Fig. 4). The Syscal Jr. Switch 48-IRIS Instruments resistivity imaging system is used in this project.

A resistivity traverse is carried out with the electrodes separated by single electrode spacing. Figure 5 shows the arrangements for a cable with eight take-outs. A convention exists in that measurements taken with adjacent electrodes connected are referred to as $N = 1a$ (5) measurements, $N = 2$ (4) to $N = 4$ (2). The numbers in parenthesis show the number of readings in each traverse. As the electrodes are all connected to the switching module, it is not required that the measurements be collected as a traverse.

At the waste disposal area, ERT surveys were carried out in four areas in order to examine and give solution in different geotechnical and environmental problems. The geoelectrical data were collected using an IRIS-Syscal Jr. Switch 48 instrument with accuracy of 0.1 mV. The system features 48 electrodes, enabling fully automated measurements of the shallow subsurface apparent resistivity using the dipole–dipole configuration. This technique has the advantage of a very good horizontal resolution, but its main disadvantage is the relatively low signal strength. Seven geoelectrical profiles were carried out which are presented in Fig. 6. The logs from four geotechnical boreholes were also used in order to verify the results in ERT1, ERT2 and ERT3. The dipole–dipole spacing a was 2–5 m enabling the possible detection

Fig. 4 Deployment of two arrays each with 25 electrodes

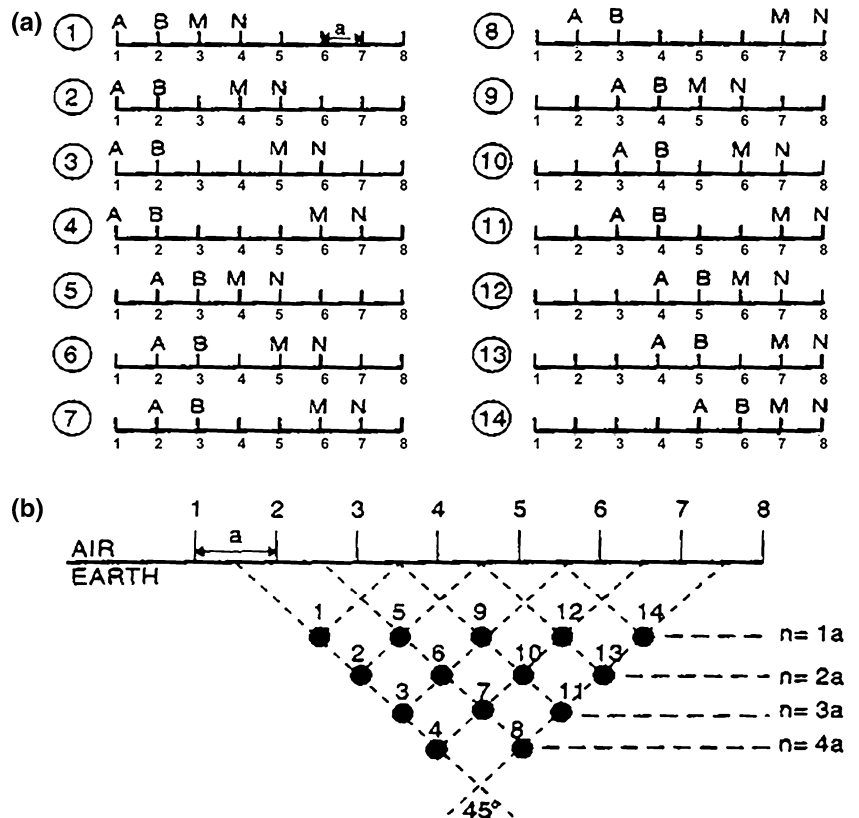


of bodies and/or structures till 30 m depth, which could be considered satisfactory for the required information about the near-surface geotechnical anomalies and potential environmental problems due to possible leakages in the study area.

The geoelectrical data collected have been processed by means of the RES2DINV (Loke 1997) and the 2DINVSCR (Tsourlos 1995; Tsourlos and Ogilvy 1999) modeling software in order to perform 2D geoelectrical data inversion. The inversion routines are based on the smoothness-constrained least squares method (DeGroot-Hedlin and Constable 1990; Constable et al.

1987; Sasaki 1989, 1992; Loke and Barker 1995, 1996a, b; Tsourlos 1995) and the forward resistivity calculations were executed by applying an iterative algorithm based on a finite element method. The inversion program divides the subsurface into a number of small rectangular prisms, and attempts to determine the resistivity values of the model prisms directing toward minimizing the difference between the calculated and the observed apparent resistivity values. The quality of the fit is expressed in terms of the RMS error. In this work, the mean RMS errors for all the conducted profiles ranged from 3 to 25%. RMS error greater than 50%

Fig. 5 Measurement scheme for the dipole-dipole measuring mode: **a** the way the data set is acquired for eight electrodes and maximum separation $n = 4$; **b** the representation of the data set in a pseudosection form. Each number corresponds to that assigned to each measurement configuration in (a)



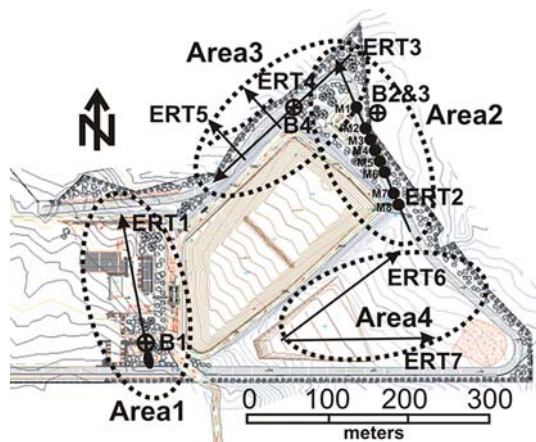


Fig. 6 A topographic map showing the four investigated areas where the geophysical measurements (ERT1–7) were carried out. The location of the observed karstic void in area 1 is also shown with *black solid ellipse*. *Black crossed circles* indicate the location of boreholes (*B1* in area 1, *B2* and *B3* in area 2 and *B4* in area 3). The location of the microtremor measurements are also given using *black solid circles* (*M#*)

(ERT tomographic image in Fig. 10) could be reasonably explained by the highly inhomogeneity of the area under investigation (high resistivity contrast between the deposits of wastes and the bedrock).

Ambient noise measurements

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 geophysical literature that using microtremors and taking the horizontal to vertical spectral ratio (HVSr), the fundamental frequency of the sediments overlying bedrock can be estimated (Bard 1999). There is still an open issue among geophysicists whether the amplitude of the frequency peak of the spectral ratio using HVSr can be identified as the corresponding site amplification. Numerous papers give contradictory results (Fischer et al. 1995; Riepl 1998), though almost all agree that spectral ratio amplitude underestimates the site amplification (Goula et al. 1998; Volant et al. 1998).

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).

Regarding the nature of the noise wavefield, at frequencies below 0.3–0.5 Hz microtremors are caused by ocean waves at long distances. At intermediate frequencies, between approximately 0.5–1 Hz, they are mainly generated both by close coastal sea waves and by the wind, while beyond 1 Hz they are linked to human activities (Bard 1999). Since the area under investigation in this study is very close to the coast, and also very close to the airport, one can expect surface waves originated at various frequencies, from 0.3 to 20 Hz, covering the frequency band of our interest.

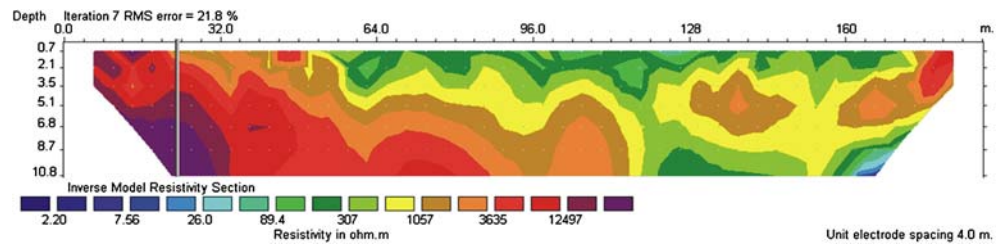
Irikura and Kawanaka (1980) report an important change in microtremor spectral characteristics when crossing a fault along a profile, proposing an explanation in terms of reflection and transmission of surface waves through a lateral discontinuity. They also proposed to use microtremor profiles as a means to detect lateral irregularities of underground structures (Bard 1999). In the area under investigation, a profile consisting of eight single station ambient noise measurements was conducted. The purpose of using microtremors was: (a) to examine if HVSr can determine cavities as lateral discontinuities and (b) to have a combination of geophysical methods over a cavity, in order to have better results. For this purpose, the microtremors profile was located at the same place where ERT2 was conducted.

The equipment used was City Shark 24-bits recorder coupled with a Lennarz 3D/5 s velocimeter sensor. All measurements had 20 min time length, using 100 Hz sampling rate. Processing of data is made using Geopsy software (<http://www.geopsy.org>). Data were filtered using a high-pass Butterworth filter at 0.2 Hz. Then time windows with constant lengths of 40 s were manually picked, in order to exclude obvious transient disturbances from nearby sources (people who walked, moving vehicles, etc.). Fourier spectra in all three components (N–S, E–W, U–D) were computed, and a cosine taper with width 0.10% was applied. Finally, smoothing of the Fourier amplitude spectra was carried out using Konno–Ohmachi algorithm (Konno and Ohmachi 1998). At the end, calculation of the HVSr for each frequency was made, in order to have the spectral ratio in the frequency band of interest, between 0.2 and 25 Hz.

Results of geophysical investigations

Seven 2D geoelectrical measurements were carried out in four areas (Fig. 6) aiming to address geotechnical, environmental and waste management problems. The

Fig. 7 Inversion model results inferred from ERT1 profile. Electrode spacing was 4 m. *Thick line* at 24 m indicates the position of the geotechnical borehole, successfully used for confirmation of the resulted model



results of tomography profiles are displayed as cross sections of the “true” resistivity distribution of the earth. Individual features, such as fractures, cavities, leakages or landfill trash cells, could be resolved. Comparison of these tomographic images with the available boring logs in ERT1, ERT2 and ERT3 and the ambient noise measurements is also given.

ERT interpretation

Area 1

In 2001 and during the foundation of buildings in the western part of the landfill (Fig. 6) a complex system of voids was discovered and remedied by applying grout curtain in every unstable/weak area.

In the light of these facts, it was decided to implement an ERT profile over a “weak” area in order: (a) to confirm the existence of the above-mentioned geotechnical anomalies and (b) to determine the spatial distribution of these anomalies since the boreholes give only local (1D) information.

The resistivity cross section resulting from the inversion analysis of the geoelectrical data (Fig. 7) exhibits significant variations of resistivity values especially at the first 32 m along the profile.

Attention must be drawn to an important subsurface anomaly characterized by high resistivity values (between 4,000 and 12,000 Ωm), which is also recognizable in the rock samples taken from a geotechnical borehole and observed from the depth of 6.5 m. The borehole is crossed by the profile at 24 m as shown in Fig. 7. Based on the shape of this body and the borehole’s log (karstic voids were obvious in rock samples), it could be reasonably identified as a possible karstic void

similar to the structures exposed during the excavations in this area, but in different scale. The rest part of the 2D model shows a homogeneity with resistivities ranging from 10 to 1,500 Ωm . The conductive area at the end of the profile is interpreted to be the beginning of the uncontrolled deposit of waste into the gorge at the early 1970s. Resistivities varying from 100 to 4,000 Ωm are indicative of the bedrock of the study area (karstified limestone).

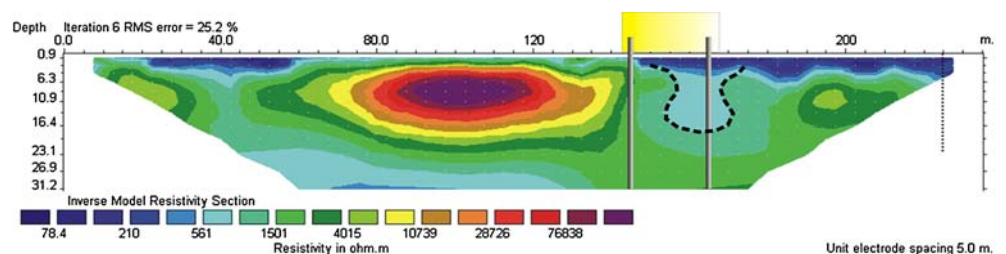
Area 2

The second area of interest is located downhill of the site, which served as the deposited area. The objective was to search out possible leakages that follow the gradient of the potentiometric surface of the groundwater.

An ERT profile (ERT2) with electrode spacing of 5 m was conducted as it is depicted in Fig. 6. The profile passed 6 m (at 145–180 m along the profile line) in front of the tanks (used for the liquid’s phase collection) and crossed over two geotechnical boreholes at 150 and 165 m along the profile line, as is shown in Fig. 8. These boreholes were used for monitoring fluctuation of groundwater level, quality control and leakages identification.

The final inversion model for profile ERT2 (Fig. 8) reveals a high resistive (20,000–80,000 Ωm) anomaly between 80 and 120 m along the profile line, which could be directly—due to its dimensions—correlated with a karstic cave. Similarly, large-scale karstic structure was recognized in the broader study area and depicted in Fig. 3. The important issue in this case is that the karstic void, which was detected from ERT2, is situated in the area where the tanks for the collection of the liquid

Fig. 8 Inversion model of the ERT2 profile. RMS error—25.2%, iterations—6. *Rectangle* depicts the area where tanks are located. *Solid lines* indicate the location of two geotechnical boreholes and the *dotted line* defines the extension in depth of the liquid leakage



phases are going to be installed. These tanks could be an enormous static load for the ceiling of the cave, which is about 4 m thick. Thus, two possible solutions to this problem were suggested. The first one was the movement of the tanks in the first 80 m of the profile and additionally, the use of geotechnical boreholes was recommended in order to check the rockmass quality and the tolerance of the specific place in static loadings.

Additionally, a low resistivity anomaly (78 Ωm) is also identified between 150 and 170 m till the depth of 16 m. This conductive zone could be reasonably assumed as the result of a leakage (see *black dashed line* in Fig. 8) from the cemented foundation of the tanks were mentioned above. In fact, the constructors reported (personal communication, 2003), that after a heavy rainfall in the winter of 2002, leachates from the landfill accumulated in this location for about 3 months. This scenario interprets the low resistivities in this complex resistive geological environment.

The resulted tomographic images were in a good agreement with the borehole logs and other geological information derived from a geological mapping of the broader area under investigation.

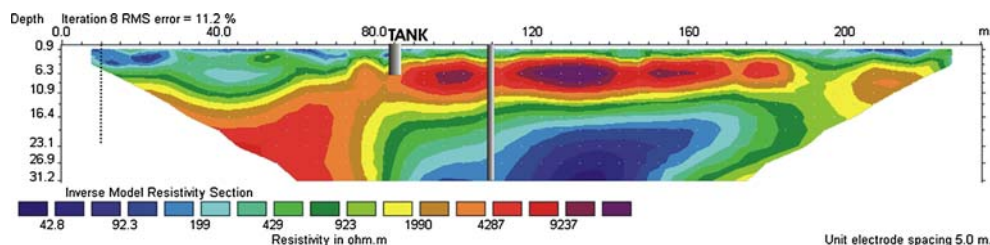
Area 3

As mentioned above, the Kouroupitos gorge used to be an uncontrolled waste deposition area since 1966. This caused serious environmental problems in the broader area, which coerced the Greek and the European authorities to define and propose possible decontamination methods in order to remedy the ecosystem.

Crucial for this action is the accurate determination of the volume of the deposited waste in the gorge. Three geoelectrical tomographies (ERT3–5) have been carried out in order to produce a crude pseudo 3D model of the subsurface in area 3, as a preliminary investigation for the design of the decontamination program.

Electrical resistivity tomography 3 resistivity cross sections resulted from the inversion analysis of the geoelectrical data (Fig. 9), indicated significant variations of resistivity values (high and low) especially

Fig. 9 Inversion model results along the ERT3 profile. The *thick line* at 110 m indicates the location of the geotechnical borehole, which was successfully used for confirmation of the resulted model. The *dashed line* at 10 m indicate the crossover point between ERT2 and ERT3 profiles



between 80 and 160 m. The spatial resistivity variation and the conductive zone in the center of the model, could be explained by a model, in which a depression of the bedrock (the supposed valley is in perpendicular direction with the axis of the gorge) is filled with wastes and covered by resistive materials, such as gravel, pebbles, etc. Two (Fig. 10) additional geoelectrical profiles (ERT4–5) were carried out in perpendicular directions (Fig. 6) to verify the results from the aforementioned tomography and to ensure our assumptions.

Conductive anomalies (0.7–80 Ωm) interpreted to be landfill deposits can be seen in the dipole–dipole tomographic data (Fig. 10). The bedrock (karstified limestone) under the landfill appears to be more resistive (80–7,500 Ωm) than the wastes. Bedrock in ERT4 and ERT5 is interpreted at a depth of 5–15 m, even though the exact interpretation is difficult because of the inversion artifacts.

Finally, combining the results from the three geoelectrical tomographies in area 3, a pseudo 3D model (Fig. 11) was constructed that represents the thickness and the geometry of the deposited waste into the gorge. Based on the information deduced from the pseudo 3D-modeling, we could easily estimate the volume of the wastes that needs to be removed in order to remedy the area. The ERT survey perpendicular to the gorge strike, could also be used to define the limit between palaeorelief and the current slope as shown in Fig. 12, by the dashed line.

Area 4

It is essential that as part of developing a landfill, the landfill applicant, whether public or private, is bound to convincingly demonstrate how a proposed landfill will be sited, designed, constructed, operated, closed and post-closure cared in order to protect the groundwater resources, public health and the environment.

In order to obey all the regulations for landfill development and under the supervision of the Department of Environmental Planning, Engineering and Management of Waste Disposal Areas of the Municipality of Chania, two more ERT surveys were carried out in the second area (area 4), which is planned to be used for waste deposit as shown in Fig. 6.

The final tomographic inversion models (Fig. 13) for ERT6 and ERT7, reveal an almost homogeneous

Fig. 10 Inversion model of the ERT4 and ERT5 profiles. RMS error—25%, iterations—9

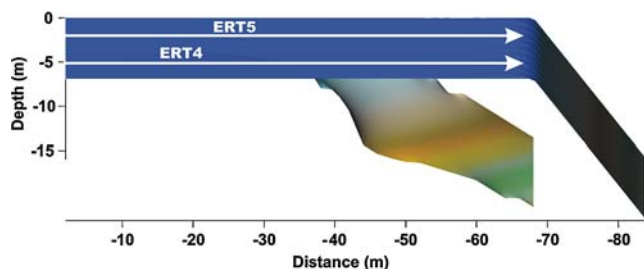
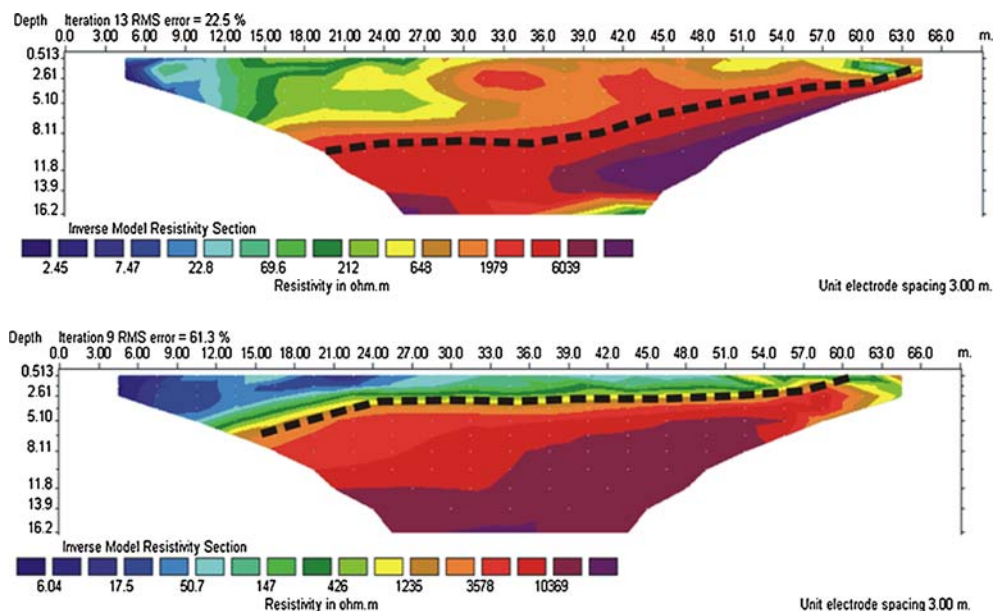


Fig. 11 Crude pseudo-3D model that represents the geometry of the limestone, which is overlain by wastes is given. The slope of the bedrock was determined using the resulted tomographic images (*black thick dashed line* indicates the interface between wastes and bedrock) as are shown in Fig. 10



Fig. 12 A photo of the Kouroupitos' gorge showing the limit between the ground (limestone) and the deposited wastes. ERT lines 4 and 5 together with the boundary between paleorelief and current slope (*dotted line*) are also depicted

subsoil, characterized by the stratigraphic transition from limestone to marly limestone with resistivity varying from 200 to 17,000 Ω m.

Microtremors interpretation

Figure 14 presents the spectral results for seven of the total eight measurements (M01 at 170 m, M02 at 140 m, M03 at 125 m, M04 at 110 m, M05 at 95 m, M06 at 80 m and M07 at 50 m). Depicting the resonance frequency from the spectral analysis of each measurement, a graph of the resonance frequency versus the location of each measurement is given as is shown in Fig. 15.

The first measurement at 35 m (M08 in Fig. 6) was removed since it was very noisy due to the wind and the continuous operation of the pump house of the storage tank of the landfill's leachates. As it can be seen as the profile crosses the assumed karstic void there is a reduction at peak frequency at both ends of the void, while at the center of it peak frequency rises at 13.4 Hz. The correlation of these measurements with the tomographic results of ERT2 profile is very good indicating that the supposed karstic void works as a resonator for the ambient noise.

The application of ambient noise measurements in such cases (surficial detection of karstic void) could be very promising since this method is cost-effective, non-destructive and easily applied.

Conclusions

This paper reports the results of a geophysical survey performed in the Municipal Solid Waste Site in Chania

Fig. 13 Inversion model of the ERT7 and ERT8 profiles. RMS errors—25 and 8%, respectively

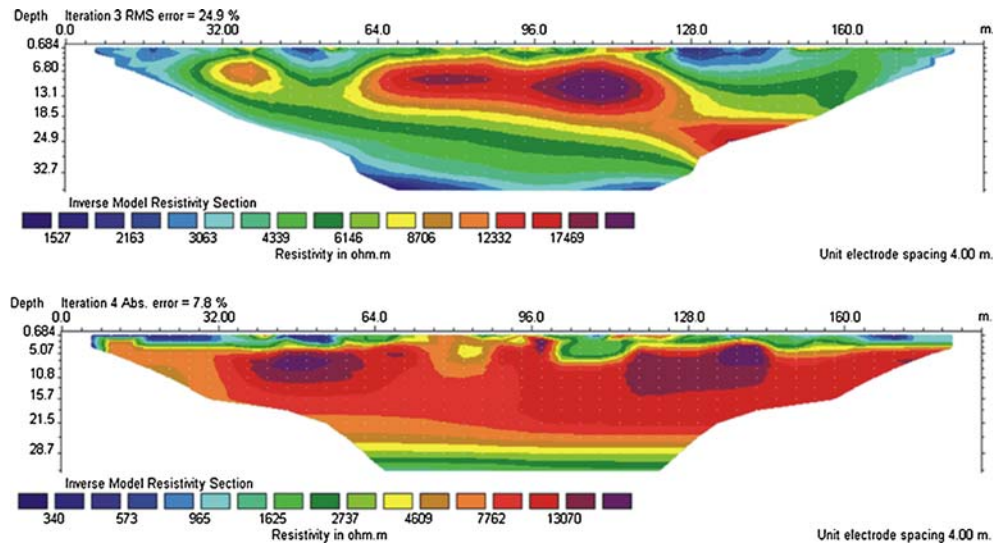


Fig. 14 Spectrum of HVSR measurements along ERT2 profile. *Shadowed areas* mark resonance frequency at most of the measurements

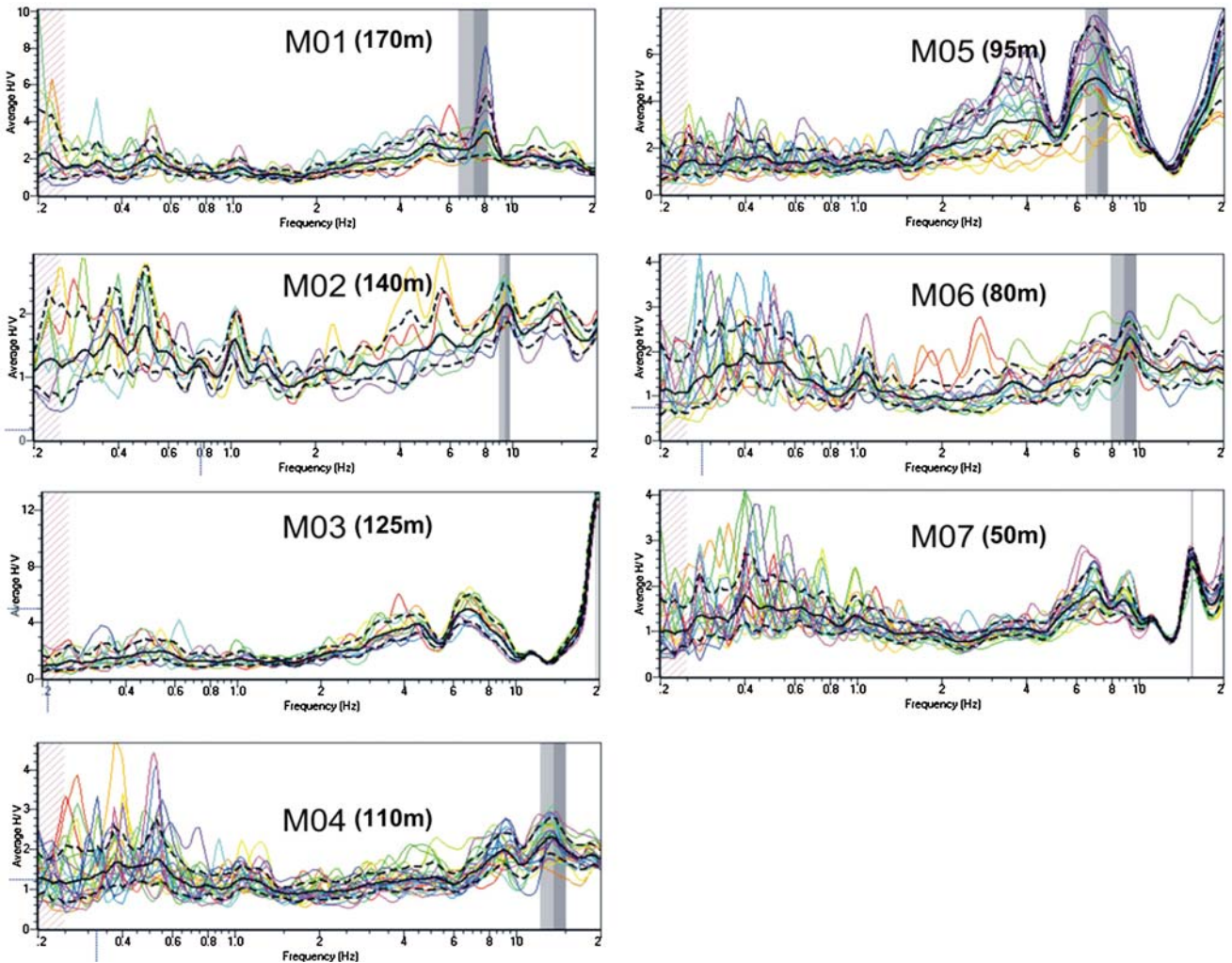
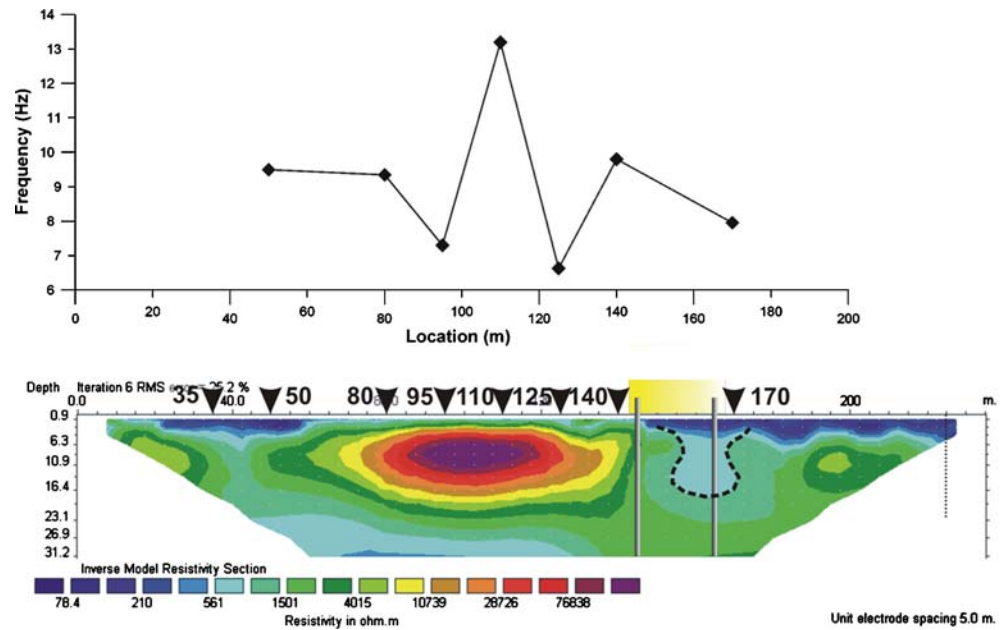


Fig. 15 Frequency peaks for seven of the total eight microtremor records versus distance over the tomographic results of ERT2 profile



(South Greece—Crete Island). The results provide evidence that the use of non-destructive geophysical techniques can be implemented in order to resolve numerous geotechnical, geological, hydrogeological and environmental problems.

It has been demonstrated that the ERT could be applicable to investigations in environmental (screening of waste disposal areas, transport of contaminants) and engineering issues (foundations of buildings, unstable/weak subsurface due to existence of voids or fractures). This method could also be used in various phases of engineering and environmental projects for determination and characterization of local geological structure. The results of the geoelectrical survey were validated through the use of the borehole logs.

The crude 3D model of the deposited wastes into the gorge, as resulted from the application of the geoelectrical methods in the area of Kourouptitos were used by site managers to support a variety of site decisions. These decisions ranged from remedy selection and design to performance optimization of existing remedies. The described survey remarkably reduces the cost and time of investigations, while the precise indication from the anomaly maps allows excavations to be undertaken only in limited sectors of the whole analyzed area

without introducing substantial modifications of the territory.

Ambient noise measurements were carried out on a sector of the studied area (area 2) over the ERT2 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. Moreover the anomaly as depicted from the frequency–distance plot (Fig. 15) was centered above the target giving an easier interpretation of its size and position. This work also introduces a new tool for the identification of karstic voids, since cave detection is maybe the first application of microtremor measurements.

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