

ERT and Seismic Tomography in Identifying Subsurface Cavities

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Summary

The use of both seismic and electrical techniques has commonly been used to detect physical properties in the subsurface. In this paper we show how using both seismic refraction tomography and electrical resistivity tomography can be used to detect subsurface voids, by looking at an application to a tunnel. The use of both techniques increases confidence in interpretation to limit inaccurate interpretation due to the large amount of heterogeneity in the near surface. The results show the location of the anomaly using both techniques.

Introduction

A subsurface cavity in the near surface includes any zone with large contrast in physical properties such as tunnels, caverns, culverts, tombs, pipes, and mine shafts. The cavities themselves are usually filled with fluid (ie. water and/or air) where we assume and are characterized with the bulk properties of that fluid. Around a man-made cavities' perimeter there is commonly a barrier material like metal or concrete as found for many in-place culverts and tunnels. The bulk properties of the barrier generally provide unique responses which it can be detected compared to surrounding rock or sediments. The difficulty in finding cavities is generally due to, 1) the size and shape of the cavity, and 2) the heterogeneity around the cavity creating similar responses.

The area of interest for this paper is in tunnel detection; the main problem associated with tunnel detection is that detection depends on local geology and history so there is no distinct characteristic. This abstract showcases two geophysical techniques that are able to detect a tunnel, seismic method and electrical tomography. Previous studies have shown that seismic methods (Halihan and Nyquist, 2006; McKenna and Ketchum, 2006; Anon., 1988) and electrical tomography (Spiegel et al., 1980; Van Schoor, 2002; Burger, 1992) can be employed to detect tunnels. The downfall to these previous studies is that their focus is on exploiting one explicit method to find and characterize the tunnel. Problems reside in inaccurate interpretation due to the complex geology of tunnel sites to properly characterize and place the tunnel. We suggest that both methods must be used in unison. Electrical resistivity methods are sensitive to the pore fluid, clay content, and presence of salts. While seismic methods are quite sensitive to mineral composition, cementation, and bulk properties. The goal of this paper is to show how tunnels may be interpreted in 1) Electrical resistivity tomography, ERT; 2) Seismic refraction tomography, SRT. The ERT tomograms will show how cavities affect the resistivity of the subsurface. The SRT images will show the velocity changes due to contrasts in elastic properties. Using both geophysical methods together limits over analysis and misinterpretation.

The work presented here is a follow up on previous work done by Hickey et al. (2009) which looked at identification and characterization of a buried pipe. He showed, even though there is a large contrast in physical properties, the effects processing seismic tomography data smeared and smoothed velocities of the void to be indistinguishable from its surrounding material. What is suggested to look at is ray tracing, analyzing the path a ray traverse from source location "a" to sensor location "b". What can be seen is that the ray coverage around the tunnel is decreased due to the low velocity creating a defocusing of affect. With this information ray coverage can be used as an indicator for a tunnel, keeping in mind this requires dense spatial sampling of shots and receivers to provide complete and reliable results. The electrical method used here was a dipole-dipole survey, chosen because of its good lateral resolution, consists of using 2 current electrodes and 2 potential electrodes. The cavity in general will be more resistive then the surrounding material, this is due to lower water content or resistive nature of the air filled cavity.

Experiment Design

Both electrical and seismic surveys were performed over a known tunnel site with good surface access. The tunnel is a ~1 mx1.6 m (3ftx5ft) concrete lined tunnel about 80m (250ft) long. In general the tunnel is approximately 6m below the ground surface at this location. The surveys performed here were all generally perpendicular to the tunnel site with the approximate location of the tunnel in the middle of the spread. The results shown here is the data collected in the ditch with approximate tunnel depth of 5-7m, the ditch consisted of unconsolidated sand.

The experiment performed was to simultaneously gather data for electrical resistivity tomography and seismic refraction tomography. The procedure involves injecting a maximum current of 1A into the ground and recording the electric potential at changing electrode spacing. Changing the spacing between the current and potential electrodes will yield greater depth of penetration. For the electrical survey a 50 electrode smart cable was used, a SARIS™ electrical resistivity imaging unit was used to apply a dipole-dipole survey. Electrode spacing of 1m with a 49m electrode spread was used; the survey after editing had 1070 measurements for the region. During acquisition of electrical data the seismic equipment was being set up with a 3m offset to the electrical survey.

The seismic refraction survey was performed using 96 GS-20DM 14Hz OYO geophones with a Geometrics Geode™ configuration and multichannel takeouts. The depth of investigation for SRT is dependent on spread length, while ray coverage depends on geophone spacing. As a rule of thumb the depth of investigation is around 1/4th the spread length. Geophone spacing was 1m with a 96 geophones used for acquisition, total spread length was 47.5m. The source consisted of a 3.7 kg (8lb) sledgehammer impacting a 10cmx10cm aluminum plate shot inline in-between the geophones, shot spacing was 1m intervals. The shot receiver set up here was then post processed with minor editing to gather and first breaks, resulting in 9312 rays.

Examples

The resistivity data here was collected then post processed using RES2D™ imaging software; the data was then edited to remove poor data. Generally for dipole-dipole surveys bad data points are caused due to poor electrode contact or not enough current injected into the ground for the potential to record. In Figure 1a we have the measured apparent resistivity psuedosection which was data gathered displayed into block format. In Figure 1b we have the calculated apparent resistivity, this uses a finite element forward model to try and describe the measured apparent resistivity. In Figure 1c we have the inverted model for the resistivity distribution in the subsurface; this is calculated by iterating the inversion process then until there is only small changes from the measured and calculated apparent resistivity psuedosections. The anomaly seen at E1 in figure 1c is the approximate location of tunnel site, the similar anomaly seen at E2 is unknown. Average resistivity for concrete ranges from 30-100 Ω m so the anomalies E1 and E2, seem appropriate for a concrete lined cavity.

The first breaks gathered were put into Rayfract™; this is a two dimensional refraction tomography travel time solver which uses ray trace theory to solve for subsurface velocities. In Figure 2a we have the velocity tomogram for tunnel site; S1 is circled to show the velocity drop down which is expected for given tunnel site. The drop down in velocity is not indicative of a tunnel site but looking at Figure 2b we can see the defocusing of waves around the tunnel location. This data was then threshold to look for minimum ray paths which can be seen at Figure 2c, the bright spot is where the approximate location of the tunnel.

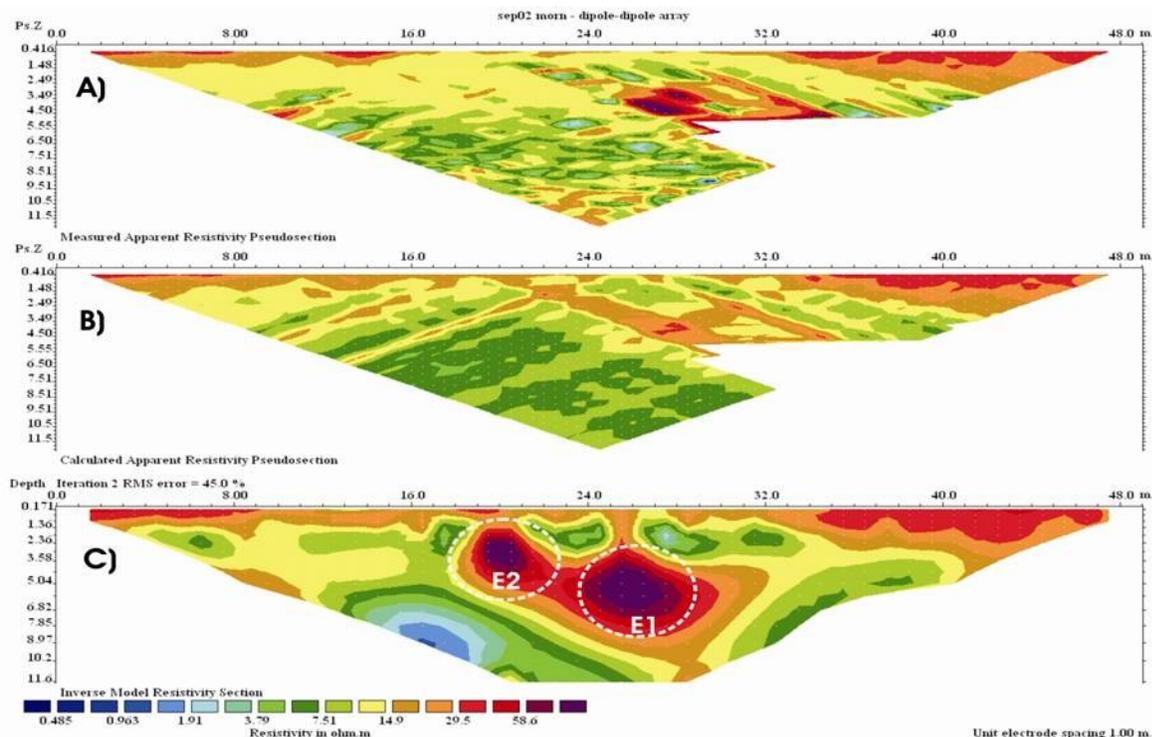


Figure 1: Resistivity tomography for the survey at a true tunnel site. A.): raw measured pseudosection of the apparent resistivity. B): calculated apparent resistivity from model resistivity; 3 iterations were used for the inversion. C): final model resistivity, this is the inverted model for the measured apparent resistivity section. Anomaly of interest is at E1, while E2 is not known.

Conclusions

The study showed that using electrical and seismic methods can be used to detect tunnels which were predicted from previous work over buried pipes. The electrical resistivity tomogram showed two similar anomalies which both could represent tunnels and without prior knowledge could have misinterpretation. The velocity tomogram showed a velocity drop down but nothing to indicate a tunnel, while the threshold ray tracing tomogram showed a tight anomaly slightly off center of the spread. The electrical anomaly in general has larger range; this is due to the smoothing during the inversion. Both methods tend to show a similar anomaly at 25.5m offset and 6m depth. Using both techniques we are more confident on the detection of the tunnel and can accurately determine the depth and location.

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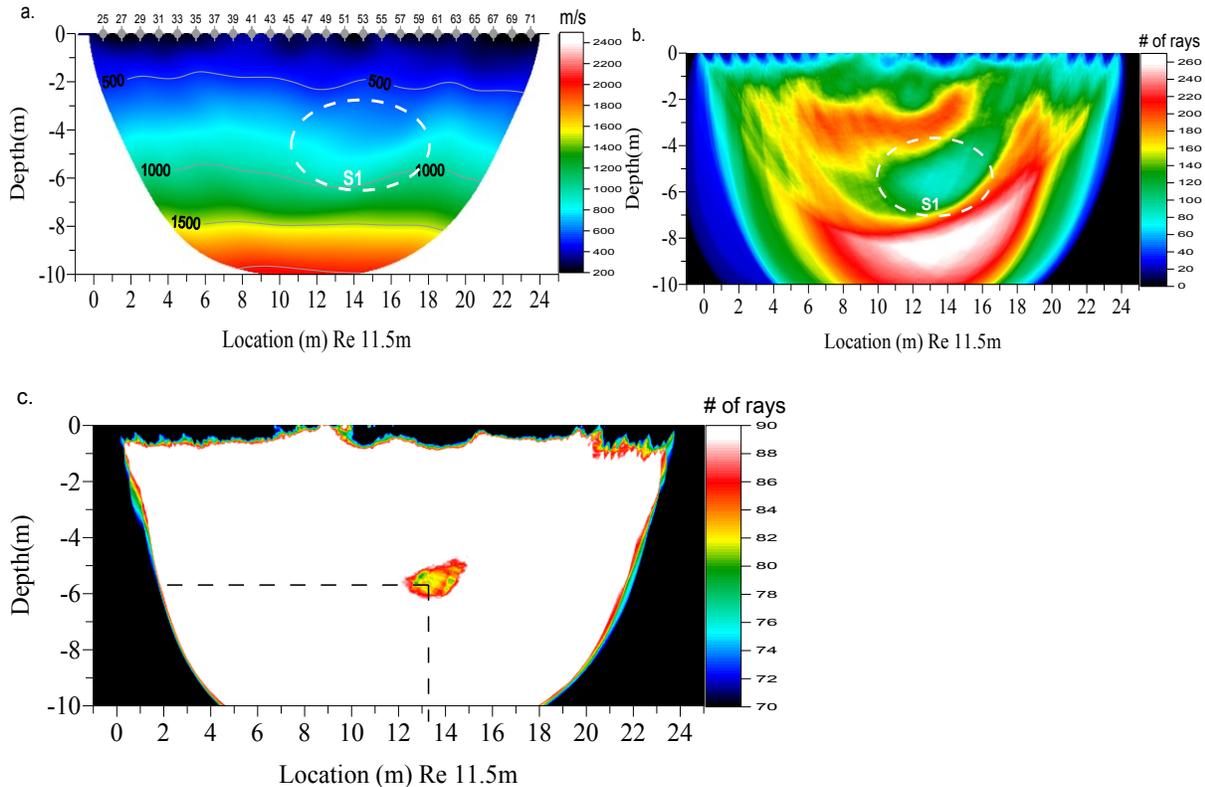


Figure 2 The data from the central part of the survey, from geophone 24 to geophone 72, processed using Rayfract™. a.): the measured velocity tomogram, b.): the corresponding ray coverage map, and c.): the ray coverage map with a threshold.

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