Detecting Underground Mines by Seismic Noise Autocorrelation and Geophysical Methods

Martín Cárdenas-Soto[1,1], Jesús Sánchez-Gónzalez[1,1], José Martínez-González[1,1], Gerardo CIFUENTES-NAVA[2,2], and David Zenil[1,1]

[1]National Autonomous University of Mexico (UNAM)

[2]UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

November 30, 2022

Abstract

Seismic noise correlation is one of the most used tools to know the earth's structure in the last decade. In this study, we used autocorrelation to determine the presence of underground mines by extracting the normal seismic response in transmission between the ground surface and the cavity roof. The experiments are carried out in the urban environment of the Mexico City western zone, where a high risk of mines collapse subsists. For this, we use ambient noise recorded for 30 min in vertical 4.5 Hz geophone arrays. We obtain zero offset sections of power spectra density from the stacking of autocorrelations in 4 s time windows. The results are compared with GPR, ERT, and seismic refraction studies. We observe that surface cavities such as drainpipe systems are present at frequencies greater than 30 Hz. Between 10 and 30 Hz, the seismic response is produced by resonances associated with cavities that can be delimited laterally by spectral maxima and whose presence agrees with discontinuities on radargrams. The mine roof depth is related to half-wavelength and the compression wave velocity of the surface layer determined by seismic refraction. The autocorrelation method does not determine the shape or vertical extent of the cavity, which is well resolved by the high resistivity values of the ERT method. However, low spectral amplitudes are observed on saturated materials where the electromagnetic wave is noisy and low resistivity values are resolved.

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Cárdenas-Soto M., J. Sánchez-González, J. Martínez-González, G. Cifuentes-Nava and D. Escobedo-Zenil
School of Engineering, UNAM - Earth Sciences Engineering Division - Geophysical Department

AGU FALL MEETING
New Orleans, LA & Online Everywhere
13–17 December 2021

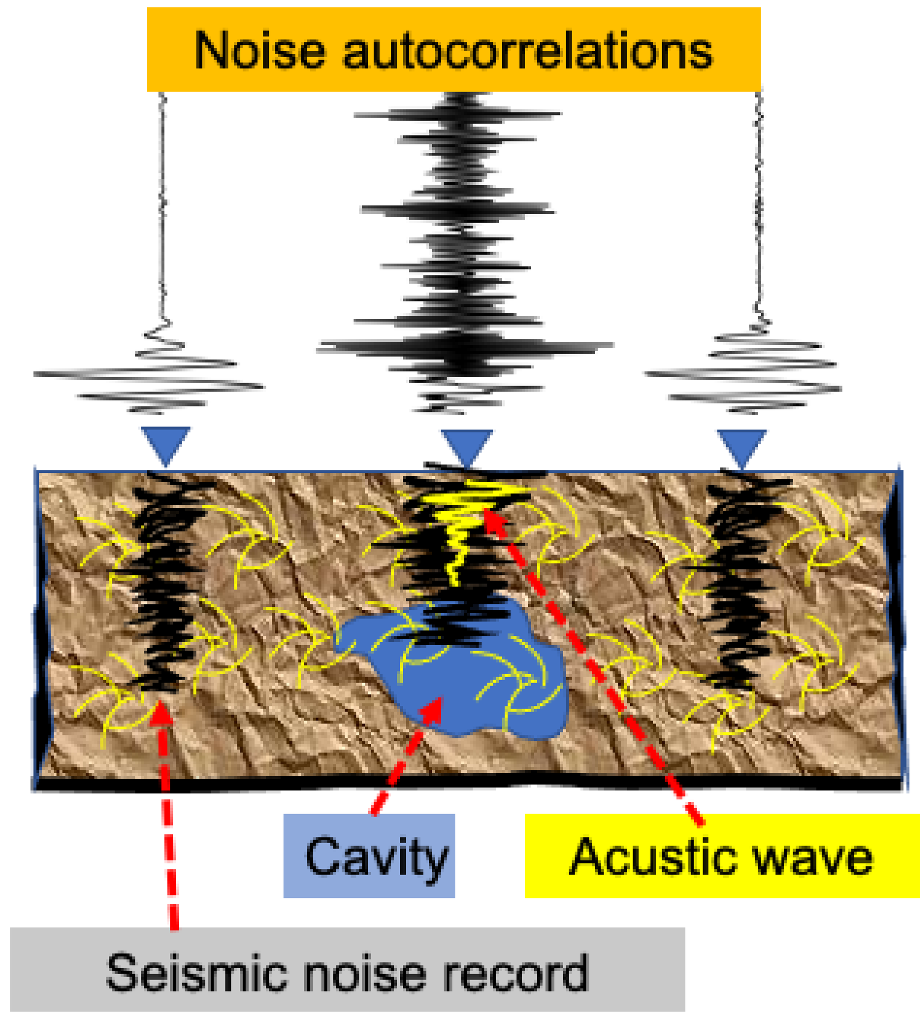
Problem Definition

Motivations: Mexico City is a densely populated city. Its western area is topographically abrupt, and the geological risk is increased because the subsoil structure is composed of vulcano-sedimentary materials, which were exploited economically in the mid-twentieth century, leaving a series of underground mines.

Goal: Use ambient seismic noise to capture the resonance produced by discontinuities in the subsoil. In special, we propose a fast and versatile method that detects the presence of abandoned mines and whose results can be compared with other geophysical methods.

Hypothesis

Main idea: We hypothesize that the seismic noise propagating between the surface and the cavity roof can generate a stationary acoustic wave (Fedin et al, 2020). Hence, the autocorrelation of noise can extract the response in reflection (Claerbout, 1968).



Data Acquisition

We collected electrical resistivity and seismic noise data in L-shaped arrays.

- An Iris instrument resistivimeter model Syscal Pro 48 Switch programmed in Wenner-Schlumberger mode was used in the ERT2D study.
- Ambient noise at 250 Hz sampling ratio was acquired using a Geometrix Geode seismograph with 24 - 4.5 Hz vertical geophones. The seismic record traces were increased by interpolating pairs of records to obtain 47 register points.
- Georadar data were acquired on one side of the array due to parked cars. ProEx System MALA GPR was used with a 100 MHz antenna.
- ERT data inversion was carried out using EarthImager2D software. GPR data processing was realized using GeoScanners GPRSoft software.

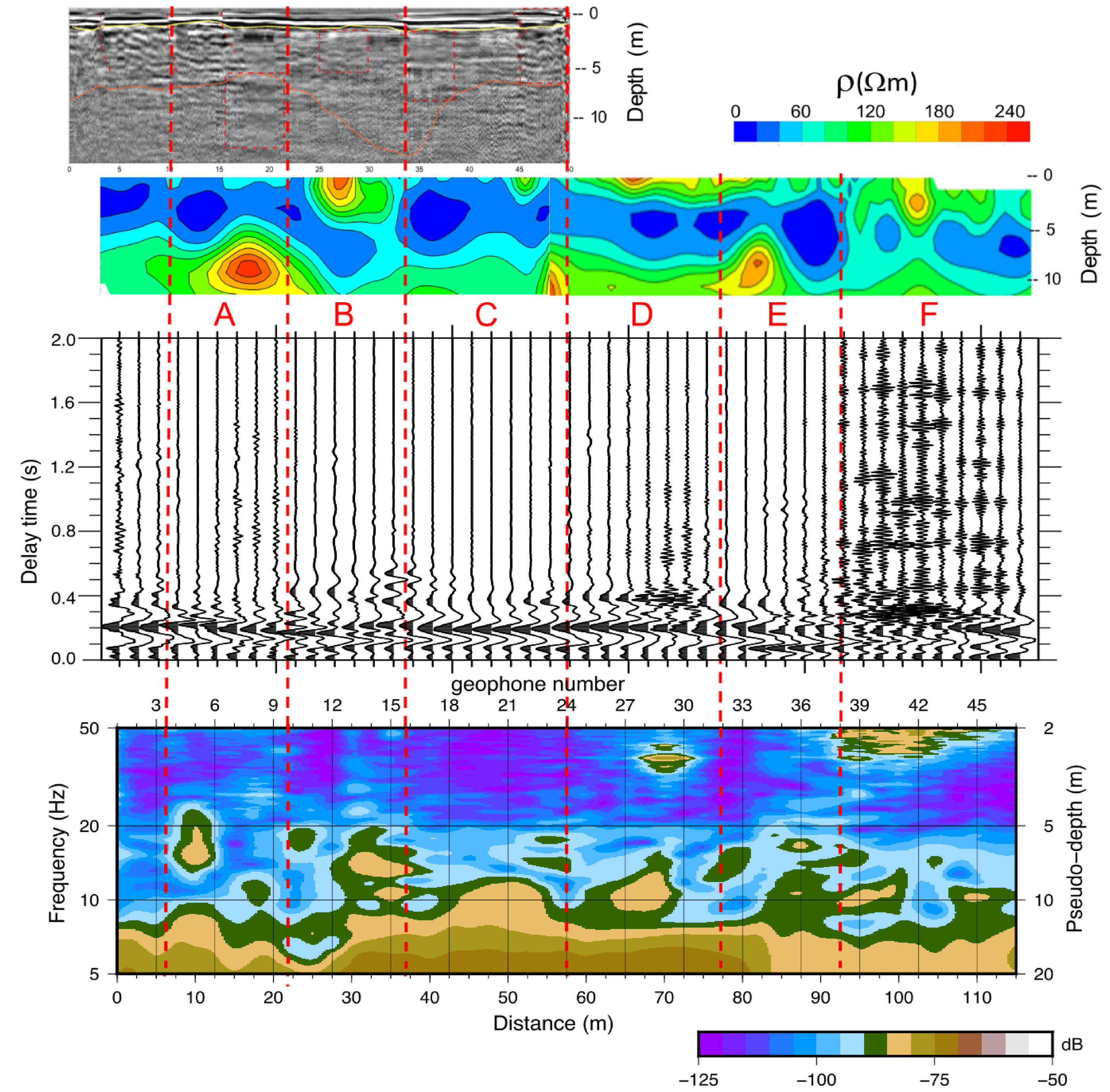
Results

ERT2D and GPR:

In the figure, we can see high resistivities close to the ground surface (zones B and F) that correspond to the presence of mines. At depths greater than 7 m, the resistive maxima in zones A and E are likely to represent a cavity. Throughout the section, there is a horizon of saturated materials. We can observe loss and distortion of the signal on the radargram due to a lack of lateral stratified continuity or high saturated materials.

Seismic Noise Autocorrelations:

We normalized the noise records (one-bit and spectral whitening), carried out autocorrelations every 8 s over 30 minutes, and calculated the Power Density Spectra (PDS). We observe the main correlation pulse (around 2 s) is almost constant except in that zones where superficial high resistivities values are present. Cavity presence could be associated in zones where the main pulse is distorted (zones A, B, E), or coda autocorrelation waveforms exhibit high-frequency vibrations (zones D, F).



The PDS image, as a function of the distance vs. frequency or pseudo-depth ($z=Vp/2f$; $Vp=400$ m/s obtained from refraction study), show C zone has fewer subsoil discontinuities; only high attenuation values (-125 dB) at frequencies higher than 20 Hz could be related to saturated materials. In zones B and F, the resonances at 15 and 45 Hz correspond to the cavity (high resistivities) observed in the ERT2D section.

The frequency of 10 Hz divides two zones. PDS values near -85 dB and below 10 Hz describe a lateral irregularity related to the high resistivities below 8 m depth. So, for frequencies higher than 10 Hz, the PDS values could correspond to subsoil alterations produced by anthropogenic activities.

Conclusions and Future Work

The seismic noise autocorrelations capture the resonance produced by an acoustic wave trapped between the roof cavity and the free ground surface. Direct and coda waves are altered by the presence of the cavity, the subsoil resonance, and saturated materials. The cavity effect appears for frequencies larger than 10 Hz. Pipes and drains systems also could be detected in frequencies more significant than 40 Hz. An L array also could be used to apply Ambient Noise Tomography (ANT, Cárdenas et al., 2020) to imaging the problematic zone and compare it with ER3D results. We are working on that.

Acknowledgement: Collaboration agreement between the Institute of Geography, UNAM, and the Alcaldía Álvaro Obregón, CDMX. Also was partially supported by UNAM-DGAPA projects: PAPIIT IN117119, PAPIME PE105520.

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