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A través de este trabajo se realizaron dos publicaciones con las cuales se participó en los siguientes congresos internacionales, el primero en "European Geosciences Union" (EGU) con sede en Viena, Austria, 2011: "**Near Surface Electrical Tomography to Detect Hazardous Areas in Guatemala City**" y el segundo en "European Assosiation of Geoscientists Engineers" (EAGE) Near Surface, con sede en Leicester, Inglaterra, 2011: "**Determine Areas of High Risk in Urban Areas (Sinkhole)**".

XY390

Near Surface Electrical Tomography to Detect Hazardous Areas in Guatemala City

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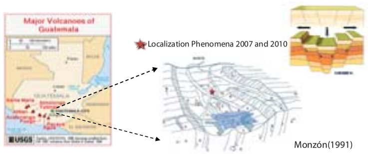
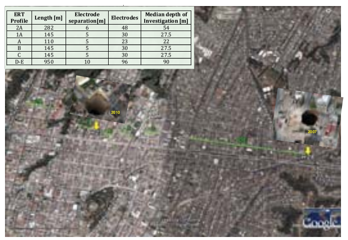
ABSTRACT

From the geological point of view, Guatemala City is considered as a pull-apart basin. Such basin had been filled up with a thick layer of volcanic sediments (ash mainly), between 100 m to 200 m thick. The upper layers are associated with a system of normal faults; induced by the 1976 earthquake and with a great influence over Guatemala City.
Two subsidence phenomena occurred in February 2007 and May 2010 in the urban area of Guatemala City. Both episodes were located over the western drainage main collector, with a few blocks apart from each other. The first one presented 25 m diameter and 60 m depth; the second 27 m and 48 m respectively; human casualties and urban damages resulted from these incidents.
In order to avoid the population's risk in the near future EMPAGUA (Empresa Municipal de Agua de Guatemala) requested to UNAM (Instituto de Geofísica de la Universidad Nacional Autónoma de México) to make the geophysical study. An Electric Resistivity Tomography was carried out along the collector trace with three different arrays (dipole-dipole, Wenner-Schlumberger, and Wenner). The field work was performed during September 2010.
A total of 1,777 m were measured and distributed into six different profiles, ranging between 110 and 960 m. Therefore the investigation depth varies between 30 and 100 m.
An IRIS Syscal 48 channels pro-switch (IRIS-France) was used to perform the study. Commercial inversion software (Earth Imager 2-D) based in the Oldenburg and Li (1994) algorithm gave the imagery for final interpretation.
In general terms, it is possible to see several areas that could represent a risk to urban facilities. On one hand there are high resistivity anomalies related to a poor volcanic consolidated material, with presence of gas or high probability of irregular caves. Other resistivity anomalies were related to highly water saturated zones suggested from the observed anomaly geometry. The water flow seems to follow the direction of natural topography which decreases from West to East (Rio Las Vacas).
The proposal for future actions suggested to EMPAGUA according to the results of this geophysical study involves the evaluation of specific sites, in order to find possible presence of saturated areas. caves, subsurface water and gas flows by means of drilling at different depths.
On the other hand it seems that the water saturated areas are not hazardous so far, nevertheless in case that the interstitial water flows away, it would leave an empty porous media, triggering a liquefaction process and a probable subsidence process.

SINKHOLES IN GUATEMALA CITY

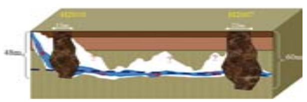
Guatemala is a Central American country bordered by Mexico to the north and west, the Pacific Ocean to the southwest, Belize to the northeast, the Caribbean to the east, and Honduras and El Salvador to the southeast. The main capital city is located in a pull-apart basin. At least 8 main volcanoes surround the city all associated with Motagua´s subsidence tectonic fault. A lot of volcanic and seismic events affected the city in recent past (i. e. Pacaya Volcano in May 2010).





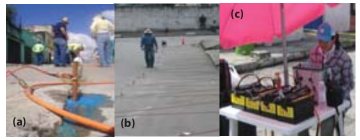
ERT Profile	Length [m]	Electrode separation[m]	Electrodes	Median depth of Investigation [m]
2A	282	6	48	54
1A	145	5	30	27.5
A	110	5	23	22
B	145	5	30	27.5
C	145	5	30	27.5
D-E	950	10	96	90

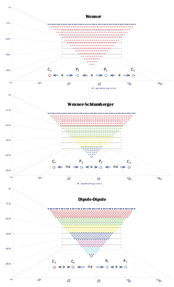
The subsidence phenomena occurred in February 2007 and May 2010 were located in a highly populated areas (6 and 2 districts, respectively). In appearance both sinkholes were related with a fail in the western drainage main collector, supposedly a rupture and/or an explosion caused by gas accumulation gave origin to these events.
During the collector's construction, several problems with the behavior of the underground were reported. Collapses of the land due to the presence of cavities and poorly consolidated materials were reported. A location map was built during the collector's construction time (Ceballos et al., 1975).



METHODOLOGY

Data Acquisition was carried out with an IRIS Syscal Pro Switch 48. Electrode layout deployed for ERT acquisition along six profiles. Drilling is done to insert the electrodes. This holes are drilled in the middle of the street to detect the drainage collector (a). Electrodes are interconnected by means of a smart cable (b) at intervals of 5 to 10m. The array finally is connected to the central console (c). A total of 1,777 m was measured.

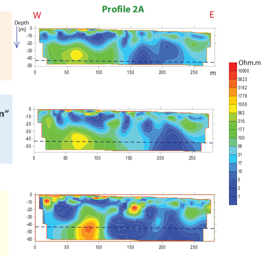




Appropriate to resolve vertical changes (horizontal structures)
Deficient to detect horizontal changes (vertical structures)
Strongest signal strength
Median depth of investigation is approximately AB/8 to AB/6 (Butler, 2005; Looke 2000)

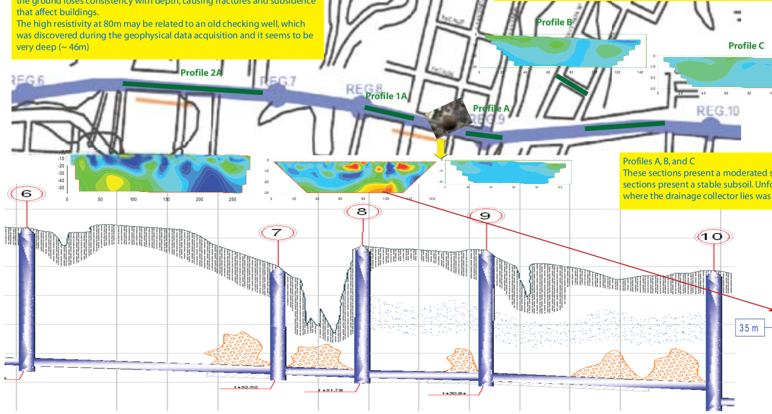
New hybrid (Pazdirek and Blaha, 1996)
Moderately sensitive to horizontal (low "n" values) and vertical (high "n" values) structures
The signal strength is, approximately, inversely proportional to the square of the "n" factor

Highly sensitive to horizontal changes (vertical structures)
Deficient to detect vertical changes (horizontal structures)
Low signal strength for large values of the "n" factor. The voltage is inversely proportional to the cube of the "n" factor.
Median depth of investigation depend of the "a" spacing and the "n" factor



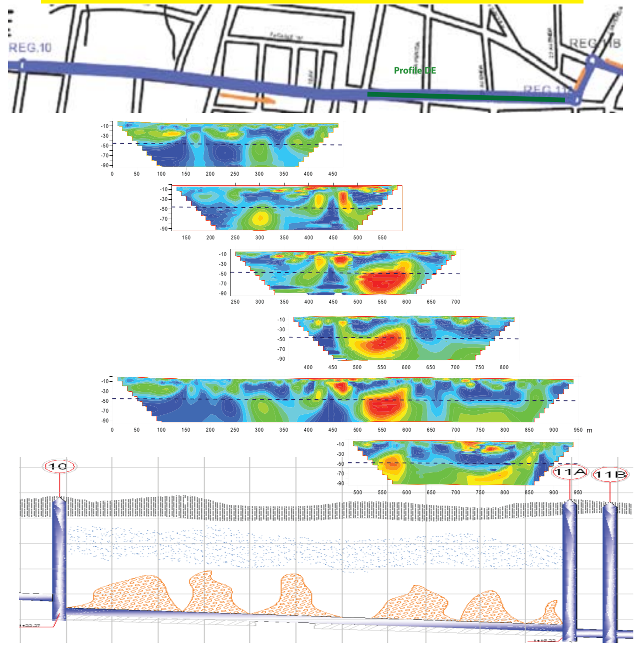
Profile 1A
Low resistivity area (1-10 Ohm.m) is presented, associated to a highly saturated water region. These represent a high risk to the urban zone, because the ground loses consistency with depth, causing fractures and subsidence that affect buildings.
The high resistivity at 80m may be related to an old checking well, which was discovered during the geophysical data acquisition and it seems to be very deep (~ 46m)

Profile 2A
A layer of low resistivity (1-10 Ohm.m) is observed. This can be related to a highly saturated water stratum, which extends throughout the whole profile following the topography and increasing its thickness in the east direction to a canyon area. At 72m horizontal, and 42m depth, a high resistivity zone appears around of 1,000 Ohm.m, that can be associate to a refilled area; could be a cavity already filled during or after the collector's construction.



Profiles A, B, and C
These sections present a moderated saturation zones. The sections present a stable subsoil. Unfortunately, the region where the drainage collector lies was not reached.

Profile DE
This profile was obtained by employing a roll along technique (five 470m profiles overlying at 75%), reaching to 90m deep. In general, we can see a complex underground, where the average resistivity is about 100 to 250 Ohm.m, which can be associated with igneous material, such as volcanic ash and pyroclastic flows, as evidenced by stratigraphy reports directly obtained from the sinkhole in 2007 (Zone 6) and in 2010 (Zone 2). The blue areas define highly water saturated areas (<30 Ohm.m), while high-resistivity anomalies in red (>10,000 Ohm.m) may be associated with possible land fill material areas or cavities (Tejero et al., 2002).



CONCLUSIONS

There was a complex underground, conformed by igneous material, product of volcanic events and heavily water saturated areas.
There is a groundwater flow that runs along the west collector following the direction of the superficial topography.
There are two high-resistivity anomalies (>10,000Ωm) in 1A and DE profiles that were associated with the presence of cavities. In the first case the cavity is empty and the second one is being verified.
It is important to verify the subsoil around the collector, in highly water saturated areas, to avoid structural problems (tubing, collector leaking by subsidence, stability, etc.).

ACKNOWLEDGEMENTS

We thank EMPAGUA (Empresa Municipal de Aguas de la Cuidad de Guatemala) for their authorization to present this work through UNAM-EMPAGUA agreement. Special thanks to Guillermo Chávez, Alejandro García, and Aide López by their participation in this project.

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P31 - Determination of High Risk Zones in Urban Areas (Sinkholes)

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(2) Facultad de Ingeniería, Universidad Nacional Autónoma de México, MÉXICO
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EAGE EUROPEAN ASSOCIATION OF GEOSCIENTISTS & ENGINEERS
Near Surface 2011

ABSTRACT

Two subsidence phenomena occurred in February 2007 and May 2010 in the urban area of Guatemala City. Both episodes were located over the western drainage main collector. The first one presented 25 m diameter and 60 m depth; the second 27 m and 48 m respectively; human casualties and urban damages resulted from these incidents.

An Electric Resistivity Tomography was carried out along the collector trace with three different arrays (dipole-dipole, Wenner-Schlumberger, and Wenner). A total of 1,777 m were measured and distributed into six different profiles, ranging between 110 and 960 m, with an investigation depth ranging between 30 and 100 m.

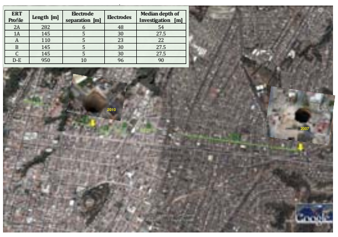
It is possible to observe several areas that could represent a risk to urban facilities. There are high resistivity anomalies related to a poor volcanic consolidated material, with presence of gas or high probability of irregular caves. Also highly water saturated zones suggested from the observed anomaly geometry. The water flow seems to follow the direction of natural topography which decreases from West to East. In case that the interstitial water flows away, it would leave an empty porous media, triggering a liquefaction process and a probable subsidence process.

METHODOLOGY

An Electric Resistivity Tomography was carried out along the collector trace with three different arrays (dipole-dipole, Wenner-Schlumberger, and Wenner). The field work was developed during September 2010.

A total of 1777 m were measured and distributed into six different profiles, ranging between 110 and 960 m. In the longest one we used a roll-along technique. Therefore the investigation depth varies between 30 and 100 m.

Data Acquisition was carried out with an IRIS Syscal Pro Switch 48. Electrode layout deployed for ERT acquisition along six profiles. Drilling is done to insert the electrodes. This holes are drilled in the middle of the street to detect the drainage collector (a). Electrodes are interconnected by means of a smart cable (b) at intervals of 5 to 10m. The array finally is connected to the central console (c).



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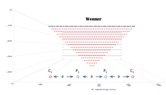
SINKHOLES IN GUATEMALA

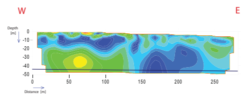
Guatemala is a Central American country bordered by Mexico to the north and west, the Pacific Ocean to the southwest, Belize to the northeast, the Caribbean to the east, and Honduras and El Salvador to the southeast. The main capital city is located in a pull-apart basin. At least 8 main volcanoes surround the city all associated with Motagua´s subsidence tectonic fault. A lot of volcanic and seismic events affected the city in recent past (i. e. Pacaya Volcano in May 2010).

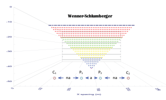
The subsidence phenomena occurred in February 2007 and May 2010 were located in a highly populated areas (6 and 2 districts, respectively). In appearance both sinkholes were related with a fail in the western drainage main collector, supposedly a rupture and/or an explosion caused by gas accumulation gave origin to these events.

During the collector's construction, several problems with the behavior of the underground were reported. Collapses of the land due to the presence of cavities and poorly consolidated materials were reported. A location map was built during the collector's construction time (Ceballos et al., 1975).

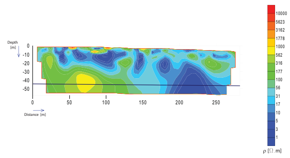


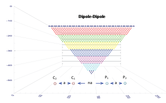
1) Appropriate to resolve vertical changes (horizontal structures)
2) Deficient to detect horizontal changes (vertical structures)
3) Strongest signal strength
4) Median depth of investigation is approximately AB/8 to AB/6 (Butler, 2005; Looke 2000)



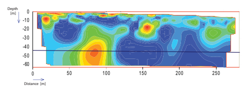


New hybrid (Pazdirek and Blaha, 1996)
1) Moderately sensitive to horizontal (low "n" values) and vertical (high "n" values) structures
2) The signal strength is, approximately, inversely proportional to the square of the "n" factor
3) Median depth of investigation is about 10% larger than Wenner
4) Probably the best array between Wenner and Dipole-Dipole.





1) Highly sensitive to horizontal changes (vertical structures)
2) Deficient to detect vertical changes (horizontal structures)
3) Low signal strength for large values of the "n" factor. The voltage is inversely proportional to the cube of the "n" factor
4) Median depth of investigation depend of the "a" spacing and the "n" factor

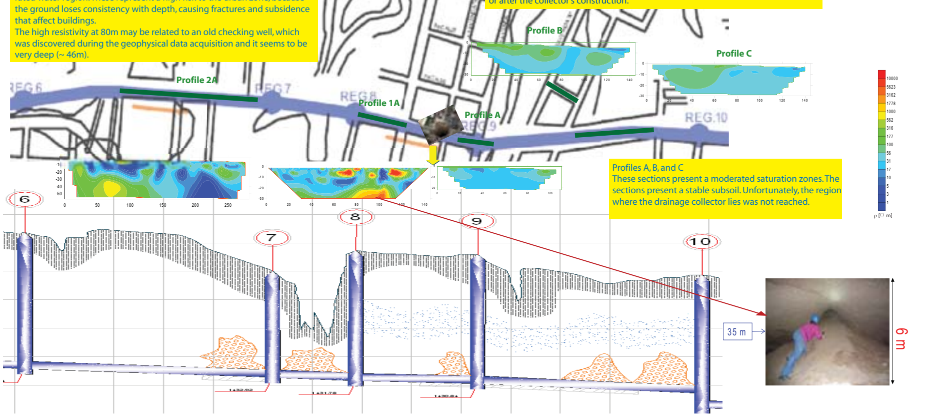


RESULTS

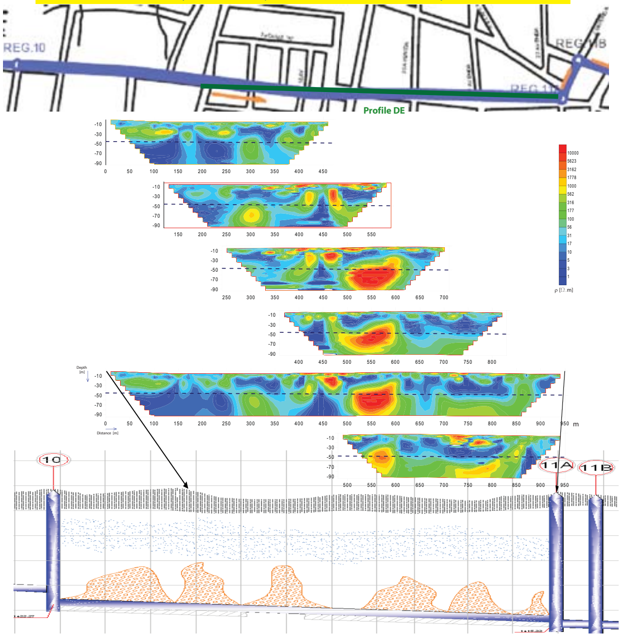
Profile 1A
Low resistivity area (1-10 Ohm.m) is presented, associated to a highly saturated water region. These represent a high risk to the urban zone, because the ground loses consistency with depth, causing fractures and subsidence that affect buildings.
The high resistivity at 80m may be related to an old checking well, which was discovered during the geophysical data acquisition and it seems to be very deep (~ 46m).

Profile 2A
A layer of low resistivity (1-10 Ohm.m) is observed. This can be related to a highly saturated water stratum, which extends throughout the whole profile following the topography and increasing its thickness in the east direction to a canyon area. At 72m horizontal, and 42m depth, a high resistivity zone appears around of 1,000 Ohm.m, that can be associate to a refilled area; could be a cavity already filled during or after the collector's construction.

Profiles A, B, and C
These sections present a moderated saturation zones. The sections present a stable subsoil. Unfortunately, the region where the drainage collector lies was not reached.



Profile DE
This profile was obtained by employing a roll along technique (five 470m profiles overlying at 75%), reaching to 90m deep. In general, we can see a complex underground, where the average resistivity is about 100 to 250 Ohm.m, which can be associated with igneous material, such as volcanic ash and pyroclastic flows, as evidenced by stratigraphy reports directly obtained from the sinkhole in 2007 (Zone 6) and in 2010 (Zone 2). The blue areas define highly water saturated areas (<30 Ohm.m), while high-resistivity anomalies in red (>10,000 Ohm.m) may be associated with possible land fill material areas or cavities (Tejero et al., 2002).



CONCLUSIONS

There was a complex underground, conformed by igneous material, product of volcanic events and heavily water saturated areas.
There is a groundwater flow that runs along the west collector following the direction of the superficial topography.
There are two high-resistivity anomalies (>10,000Ω m) in 1A and DE profiles that were associated with the presence of cavities. In the first case the cavity is empty and the second one is being verified.
It is important to verify the subsoil around the collector, in highly water saturated areas, to avoid structural problems (tubing, collector leaking by subsidence, stability, etc.).

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