ELECTROMAGNETIC, GPR AND THERMAL MAPPING OF SINKHOLES FOR GROUND REINFORCEMENT

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Abstract

The city of Helsinki is expanding and building new residence areas in places which may have been filled for long periods of time with heterogeneous ground and infillings. One of these areas, named Jätkäsaari, is an artificially expanded island that is under construction. It has been observed that small sinkholes (extent ~ m^2) have appeared in unexpected places, and that the subsurface soil matrix transportation process is driven by sea water level fluctuations. There is the need to locate developing sinkholes for ground reinforcement actions.

An electromagnetic (EM) short coil spacing instrument, ground penetrating radar (GPR) and airborne thermal imaging were used to test at a selected property area of interest in October 2016. The size of the area mapped in detail with EM and GPR was 4120 m^2 and the size of the area with thermal imaging was larger than 10000 m^2. The objectives were to locate sinkholes at the site, study how various methods suit to mapping, how consistently the results fit together, and derive recommendations for future use.

EM multifrequency and GPR data was first interpreted by classifying the identified objects and by subsequent joint interpretation. Airborne thermal imaging also located multiple spots to be assessed. Most of the potential areas covering GPR and EM objects occupied 16.5 % of the site.

Objectives and site setting

The city of Helsinki is expanding and building new residence areas. Jätkäsaari is an artificially expanded island that is under construction. It has been observed that small sinkholes (extent ~ m^2) have appeared in unexpected places (Figure 1), and that the subsurface soil matrix transportation process is likely driven by sea water level fluctuations. Varying grain sizes of fill materials, high porosities and rainfall can accelerate the phenomena.

The objectives were to locate cavities and loose ground at the site, study how various methods suit to mapping, how consistently the results fit together, and derive recommendations for future use. Site geotechnical drillings had identified at 0 – 7 meters various types of earth fill; then below that, silt and sand and, finally, a bottom moraine layer. The ground surface was flat; the surface soil was coarse fill or asphalt partly overlaid by 0 – 10 cm silt-sand. Contaminated soils were known to exist in the area. The groundwater was at depth of 2.6 – 3.0 m during the survey.

Field arrangements and measurements

A suitable available and relatively empty site was selected for measurements where a public school is to be constructed. The original intention was to map an area of about 10000 m^2. That was considered as practical and representative of what should be surveyed as a minimum per case.

All field measurements were scheduled for one week and actions to completely empty the area and keep it empty were started two to three weeks before that. An area of around 6000 m^2 was emptied and shut off in the beginning of the line set up and for markings. The measurement area consisted of a 70 x 52 m main area and an attached additional area 20 x 24 m, totalling 4120 m^2. During measurements the location of influential subsurface objects like cables, metals, drain covers was noted. Because intensive construction was going on and parking and storage places were short, one person had to devote a significant part of the time controlling unauthorised parking, opening and closing taped lines and keeping the site empty. During the measurements period any remaining metallic small parts and other debris found was temporarily removed.

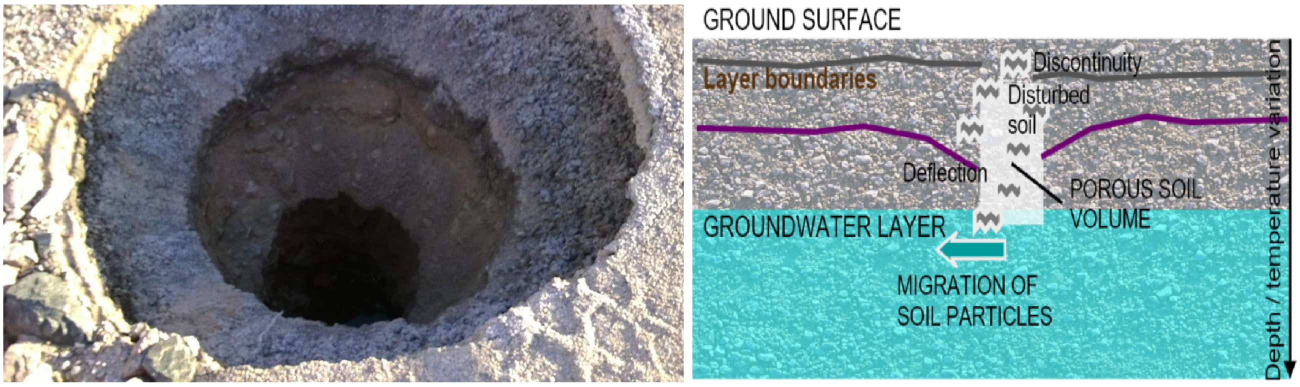

Figure 1: Outcropping cavity at Jätkäsaari island, at distance 40 meters north from the investigation area northeastern corner. Methodological model is illustrated on the right.

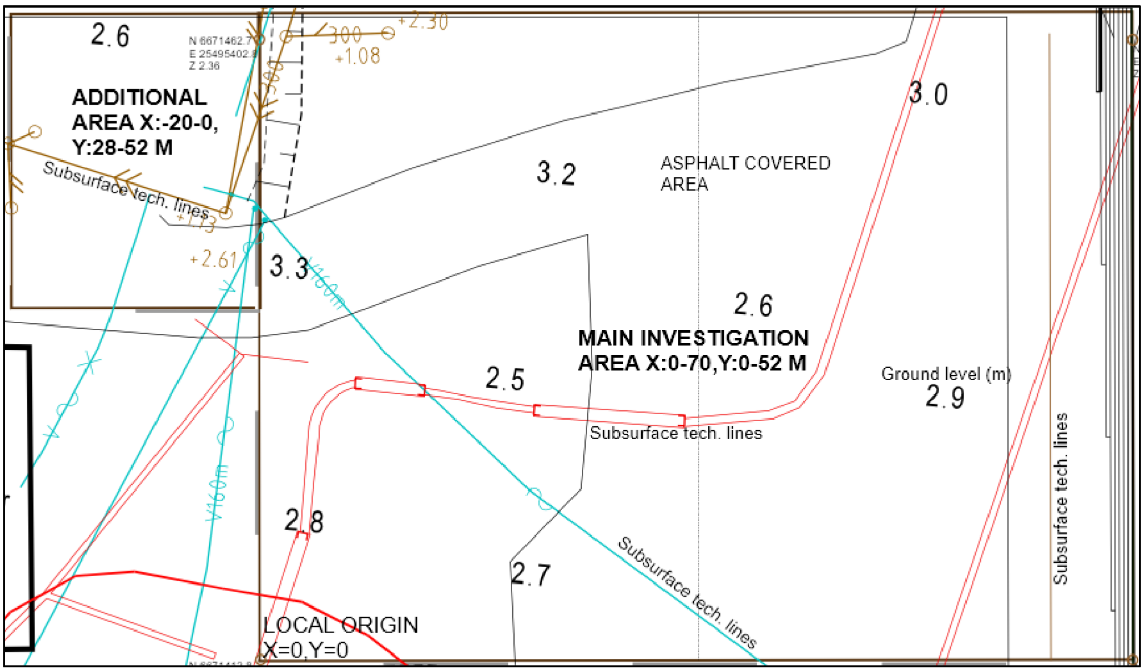

Figure 2: Site map showing area for GPR and EM measurements. The thermal imaging covered also an area of around 20 – 40 meters.

GPR with a 250 MHz antenna and EM profiling with 4, 8 and 16 kHz frequencies were taken along parallel lines having 1.0 m separation. The sampling interval with GPR was 0.07 m and with

EM in continuous mode at 0.7 – 1.3 m and recording height of 0.2 m. For ground measurements the relative positioning accuracy was between 0.5 – 1.0 m within the local grid.

Airborne thermal imaging was done after the ground measurements during midnight and in non-windy and dry weather T = 0 – +1 °C from height 90 – 95 meters with UAV equipped with FLIR 9.0 camera and utilising a set of parallel flight lines. Weather in late October had been dry, so ground surface was dry and water content varying a little as possible. Two short DC Schlumberger soundings were carried out for ground structuring and to gain resistivity level confirmation.

Data processing and interpretation

The methodological basis is described on the right in Figure 1. First GPR and EM data was tied to local coordinates and recording positions were adjusted. Project processing was determined for GPR and traverse was adjusted with distance markers. Along GPR lines all reflector anomalies that can be related to cavities were picked and classified as to types: disturbed ground, layer deflection, discontinuity in layering, vertical structure/surface and other objects like metals, boulders etc. Hyperbolic features were classified as vertical structures. Particular attention was paid to soil layer continuities because cavities and soil material flushing cause local disappearance of layer boundaries or result in downward deflections. Anomaly size classes were point like (length < 2 m) or larger and anomaly magnitude classes were weak, medium and strong. All surface topography variation related anomalies were removed from interpreted objects as well as objects associated with certain subsurface technical lines. All together 120 potential objects were interpreted, one per each mapped 35 m^2 as an average. Five GPR objects appeared as having most potential for cavity or sinking ground: two nearby layer deflections in the additional area, one vertical structure at the area's northern edge and two deflections in the southern part of the area (Figure 3).

EM data Re- and Im-component values were processed with levelling and drift adjustment. Instrumentation was calibrated on-site and a tie point was used to assess standard deviations, adjust drift and do fine-levelling. In processing outlier correction or data component rejection was applied. Im-components were converted to apparent resistivities and Re/Im-component ratios were calculated for the remaining 4048 points. In EM data interpretation resistive small size targets consistent at all frequencies were picked. The first interpretational model was based on higher resistivity classes per frequency (derived from standard deviations), overlaid in maps with varying RGB intensities for three frequencies, respectively. However, there were also many Slingram-type small object anomalies where local minimum (high resistivity) situates over the conductor. So anomaly shapes and Re/Im-ratios had to be considered and taken into account in the final sorting of resistive points.

In thermal data processing images were combined to a few subarea maps. For positioning 9 points were marked with hot water containers and temperatures at ground surface were measured for control. After calibrations thermal data deviated less than ±0.5 °C from control point temperatures. From the maps, spots indicating higher local temperatures from +0.5 – +2.0 °C were picked up. Temperature anomalies were also compared to values measured from the insides and bottoms of five surface runoff wells having from +2.0 to +4.5 °C higher values than the shallow ground. Thus detected temperature anomalies are realistic and can be used to indicate upward heat flux from deeper soil.

Finally interpreted sinkhole or loose ground locations were identified from three methods. In Figure 3 all interpreted objects and their types are summarised: GPR as objects, EM as resistive areas per frequency and thermal warmer spots. Altogether 12 discrete areas and three separate significant GPR objects represent susceptible holes, porous or disturbed ground. All of these covered 16.5 % of the investigated area. In addition, one potential waste fill (violet bounded, Fig. 3) 200 m^2 area was outlined. Any clear indication of a cavity within the investigation area was not deduced from the results.

Because many metallic object indications were detected, it led to a spin-off result for the client. A map from EM Re/Im-ratio data was derived to indicate good conductors as metals. In areas filled with heterogeneous materials and debris, buried metallic objects ranging from decimeters to even tens of meters can exist. Metals can cause damage in drilled-piling and borings, for example. Avoidance of metal occurrences can lead to considerable savings. However, in drilled-piling to a depth of 10 meters or more only larger objects with increasing burial can be detected.

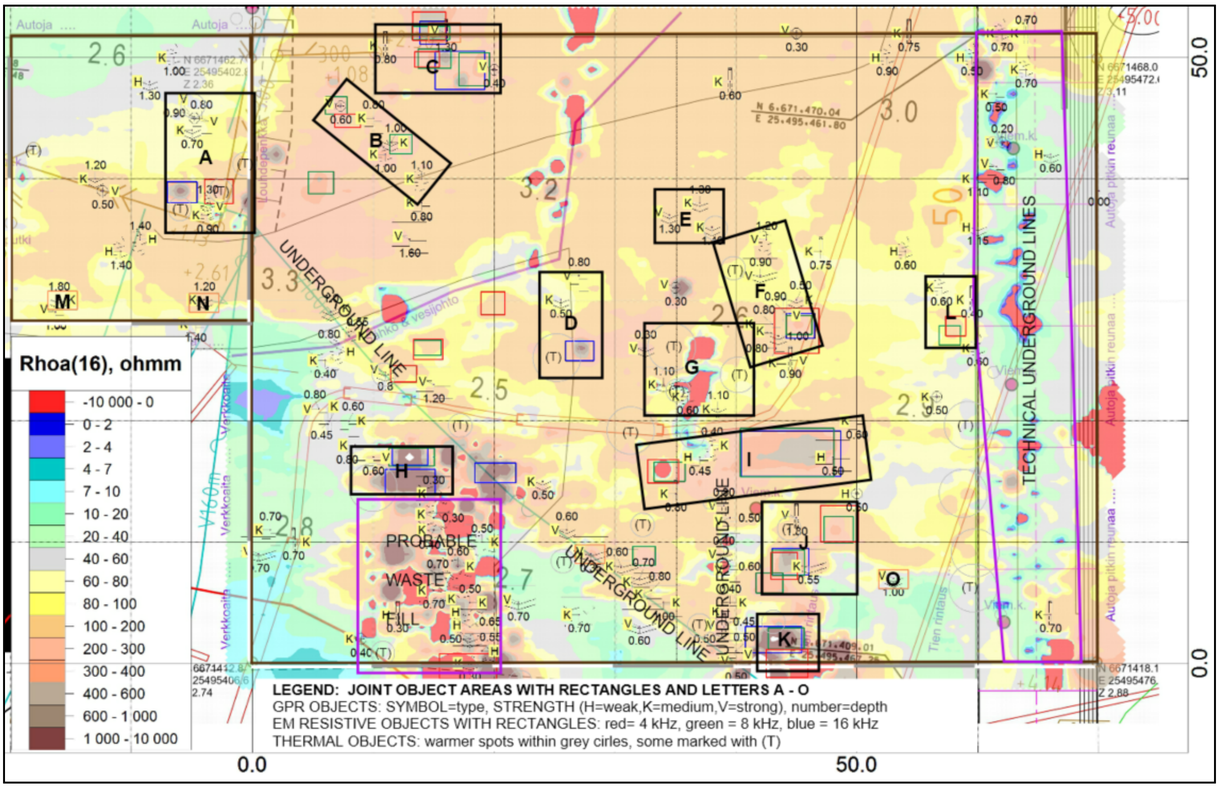

Figure 3: Joint interpretation map for GPR, EM and thermal object locations and types, areas A – O. EM apparent resistivity Rhoa(16) map in the background shows locations of small metal objects as negative (red) values.

Conclusions

Results indicated that there were not likely sinkholes that were over one meter in diameter at the study area and close to outcrop. EM or GPR can be used efficiently for detailed cavity and loose ground mapping, and thermal imaging suits better for larger scale pre-mapping. EM revealed also one probable waste disposal fill as subarea. Indications of metallic subsurface objects were also recorded. This information can be useful in directing reinforcement activities and in avoiding damage in drilled-piling.

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