LANDFILL CHARACTERIZATION BY MULTI-METHOD GEOPHYSICAL INVESTIGATION: THE CASE STUDY OF LEPPE (GERMANY)

Tom Debouny¹, David Caterina¹, Itzel Isunza Manrique¹, Pascal Beese-Vasbender², Frédéric Nguyen¹

¹ University of Liege, Urban and Environmental Engineering, 4000 Liege, Belgium (tom.debouny@uliege.be)
² Bergischer Abfallwirtschaftsverband, Braunswerth 1-3, 51766 Engelskirchen, Germany
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LEPPE LANDFILL DESCRIPTION

- From 1892 to 2004: Municipal solid waste (MSW) deposit in areas DA1, DA2, DA3 and DA4, overlaying a geological host mainly composed of sandstone, siltstone and mudstone.

- Since 2005, only ash MSW incineration deposited in DA4 and DA5 on top of the prior MSW and in mono-deposition in DA6.

- A landfill capping in DA1 to DA5 enables the extraction of biogas to a rate of about 450 – 500 m³/h.


- Due to logistical and infrastructure constraints (i.e. complete cone built from incineration ash, geomembrane), the geophysical survey focused on the DA4 zone, underneath the cone.
**ERT/IP**

- **Objectives:**
  - Resistivity distribution: Discrimination of different waste types and investigation of changes in leachate content
  - Chargeability distribution: Detection of metallic scraps or zones of higher organic content

- **Measurements:**
  - Two nearly parallel profiles, spaced of 55 m at the bottom part of the landfill cone, each containing 64 stainless electrodes with a spacing of 3 m
  - Data acquisition with a combination of a dipole-dipole array ($n$ factor = 6), a gradient array ($s$ factor = 8) (Dahlin & Zhou, 2006) and a bipole-bipole array
  - Inline and crossline measurements
  - Repetition of measurements to estimate the repetition error and collection of reciprocal measurements at each profile to assess of data quality
ERT/IP 3D MODELS

- **Resistivity:**
  - Surface artefacts close to the electrode positions
  - Very low global electrical resistivity observed (98.9% <100 Ohm.m)
  - Lowest values in the western part of the model (<10 Ohm.m)
  - Acute contrast in the chargeability model

- **Chargeability:**
  - Log$_{10}$ ρ (Ohm.m)
  - Log$_{10}$ ρ (Ohm.m) Chargeability (mV/V)

Chargeability (mV/V)
**ERT/IP 2D Slice Cut**

- **Resistivity model:**
  - Exhibits a lateral contrast
  - The lower resistivity zones may be related, in general, to a higher content in ash and household wastes
  - The higher resistivity zones may correspond to a higher content in inert materials and to the geological host
  - The vertical resistivity contrast does not allow the base of the landfill to be inferred

- **Chargeability model:**
  - Shows a more pronounced variability with depth
  - The low chargeability may characterize the inert waste
  - The medium chargeability may correspond to the household waste
  - The high chargeability might be related to the geological host

- **Sensitivity model:**
  - In zones of low sensitivity, the contrast is attenuated and does not allow to accurately image the interface
MASW

- **Objectives**:  
  - Characterization of the shear wave velocity structure of the subsurface indicating layers of different waste composition and the transition to the host material

- **Measurements**:  
  - One profile deployed between the geoelectric profiles on a smooth topography zone  
  - Fixed receiver array of 48 vertical geophones (4.5 Hz natural frequency) at 2 m intervals  
  - Source moved every two geophones (4 m) from one extreme of the profile to the other  
  - A total of 20 shots was stacked at each shot point
**MASW 2D SHEAR WAVE VELOCITY MODEL**

- **Three main heterogeneous layers:**

1. Characterized with intermediate velocities between 400 and 500 m/s; Might be related to the topmost ash layer.

2. A thicker layer of low velocities from 150 m/s up to approximately 350 m/s; Might correspond to the intermediate household waste.

3. In the bottom part (275 m elevation), increase in velocities up to 700 m/s; Might represent the natural soil beneath the waste deposits (in accordance with old topographic maps).
Objectives:
- Estimation of the thickness of the waste and/or different material deposits depending on the mechanical contrast with the underlying media

Measurements:
- Acquisition with a three-component sensor with a low cut-off frequency of 1 Hz (seismometer LE-3Dlite MkIII Lennartz)
- Ambient noise recorded at 17 locations along the upper ERT/IP profile
- Spacing of 12 m between each station
- Recording time set to 20 minutes
Hvnsr 2D Fundamental Peaks Profil

- Interpolation of the H/V amplitude along the position of all the stations to visualize the fundamental peak(s) and their continuity along all the stations.
- For almost all stations, one fundamental peak centred around 1.5 Hz; Might be associated with a layer at a larger depth.
- Between station 4 to 8 and the last one, other contributions are also observed at frequencies around 20-50 Hz; Might be associated with a layer at a shallower depth.
HVNSR THICKNESS ESTIMATION

- Transformation of the frequencies linked to two fundamental peaks \( f_{\beta_1} \) and \( f_{\beta_2} \) to roughly determine \( h_1 \) and \( h_2 \) thicknesses along the H/V profile

- Use of the shear velocities estimated during the MASW (\( \beta_1 \) and \( \beta_2 \)) and the formulas (Piña-Flores et al., 2017):

\[
\begin{align*}
  f_{\beta_1} &= \frac{\beta_1}{4h_1} \\
  f_{\beta_2} &= \frac{1}{4\left(\frac{h_1}{\beta_1} + \frac{h_2}{\beta_2}\right)}
\end{align*}
\]

- The estimated bottom limit fits the original topography before the MSW disposal

- A shallowest layer only present for the intermediate and last stations, as the associated fundamental peak was not continuous
CONCLUSION

- **ERT/IP:**
  - Delineation of inert waste from household/ash deposits
  - Not sensitive enough to individually identify and locate these materials with certainty
  - The IP method remains more promising for the estimation of waste types and volumes in zones with good coverage

- **MASW:**
  - Detection of three distinctive layers (ash, MSW, geological host)

- **HVNSR:**
  - Estimation of the bottom layer in good agreement with the topography known before landfilling

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REFERENCES

- Dahlin, Torleif, and Bing Zhou. 2006. 'Multiple-gradient array measurements for multichannel 2D resistivity imaging', *Near Surface Geophysics*, 4: 113-23.7