PEGGHy - Platform for Experimental Geophysics, Geotechnics and Hydrogeology of the Graduate School of Geological Engineering, Nancy, France

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ABSTRACT: Students in geo-engineering need to master the complex structuring, properties and behaviours of the underground. In addition to geological observations, pedagogical field works can involve the deployment of instruments for dedicated measurements to characterize and monitor a specific site. However, surveys are often carried out with a limited knowledge on the geometry of the underground structure, so discussing the accuracy and limitations of the prospection methods in a robust and quantitative way is tricky. To circumvent this major issue, we have developed the Platform for Experimental Geophysics, Geotechnics and Hydrogeology (PEGGHy), which holds "artificial", fully controlled geological structures and heterogeneities. PEGGHy is filled with aggregates which have been selected based on i) their lithological properties so that significant geophysical contrasts are expected, and ii) their porosity and permeability to provide heterogeneous fluid flows. In addition, the base of the pit and the top of some folded layers are sealed by geomembranes to create both a confined reservoir and a free aquifer. Thanks to photogrammetric data acquired by drone, PEGGHy goes with a 3D, centimetric precision digital twin. Such a numerical tool allows to quantitatively compare models derived from geophysical, geotechnical and/or hydrogeological data with the true subsurface geometry. It also allows to run various modelling codes and confront their results to real data, providing a unique opportunity to teach and test numerical schemes, discretization algorithms and auscultation methods.

Keywords: Experimental Platform, Applied geophysics, Geotechnical engineering, Hydrogeology, Digital twin

1 Introduction

Engineers in geosciences need to master the complex structuring, properties and behaviours of the underground. To emphasize this complexity, all educational training in geosciences include "field" periods to acquire, describe, understand and model data from either natural or man-made environments. In addition to geological observations, field works can involve the deployment of instruments for dedicated measurements to characterize and monitor a specific site, estimate the associated risk and environmental issues, and support decisions of our future engineers.

Geophysical, geotechnical and hydrogeological measurements allow estimating petrophysical parameters of soil and underground materials. However, fieldwork and surveys in geosciences are often carried out with a limited knowledge on the geometry of the underground structure, so discussing the accuracy and limitations of the prospection methods in a robust and quantitative way is tricky. To circumvent this major pedagogical issue, we have developed the Platform for Experimental Geophysics, Geotechnics and Hydrogeology (PEGGHy), which holds “artificial”, fully controlled geological structures and heterogeneities. The platform is located near the *École Nationale Supérieure de Géologie* (ENSG) campus at Vandœuvre-lès-Nancy, France. It has been conceived as part of a collaborative initiative by the ENSG teaching team, with significant contributions from faculty members overseeing the Applied Geophysics (authors: P. Cupillard, J. Sausse, Y. Géraud and M. Diraison), Hydrogeology (authors: F. Golfier and C. Oltéan) and Geotechnical Engineering (authors: A. Abdallah and O. Cuisinier) programs. This document reflects the pedagogical vision shared by the authors and, more broadly, by the ENSG teaching team.

In the first part, the content and the geometry of the PEGGHy geological units are presented. These units are equipped with optical fibers which are described in the second part. Then, the 3D digital twin of the platform derived from photogrammetric data of the construction site is detailed. Finally, the pedagogical perspectives that PEGGHy opens in terms of geotechnical and geophysical studies are discussed using examples. Because boreholes and piezometers are missing at this stage, hydrogeological aspects are not included.

2 Technical design of the platform

PEGGHy has been built in two steps: 1) the excavation of a 60m long, 20m wide and 2.5 to 4m deep pit, and 2) its finely controlled filling (i.e., using centimetric precision GPS) by a stack of various rock aggregates which mimics sedimentary layers of different lithological and petrophysical nature (Table 1). Some of the layers are horizontal whereas some others are folded. Moreover, they are shared between two compartments separated by a fault. Such a design leads to physical interfaces and a specific geometry representing main natural geological objects on a reduced but significant scale (Figure 1). The total excavated volume is of the order of 4 600 m^3.

In addition to specific physical properties, the materials have been chosen with respect to the proximity of quarries to the project site, for both educational and ecological reasons:

- **Host carbonate rocks of ENSG site**

The ENSG site is built on Jurassic limestone, with very little vegetal soil on top of it. This formation consists of oolitic limestones of the “Polypiers inférieurs” (Bajocian). These are micritic and/or oolitic and bioclastic limestones stratified in horizontal beds with often oblique internal stratification. The limestones were excavated, crushed on site, and then placed back in the pit to build the base of a fold.

- **Alluvial siliceous sands of the Hériménil quarry (company Vicat)**

These are crushed siliceous alluvium corresponding to mix of sands and pebbles attributed to the Fxb3M alluvium. The Fxb3M alluvium has been extensively exploited along the Meurthe river valley. The deposits are highly sandy, with gravel and pebble fractions predominantly concentrated in the upper layers. The granite and gneiss constituents exhibit an advanced degree of weathering with widespread mineralogical alteration.

Two grain sizes have been selected: a fine one for a sandy aquifer formation (0-5 mm) and a coarser one (20-80 mm) for a water retention basin (30% porosity) for future hydrogeological testing.

- **Basaltic gravels « trapp » of the Raon l‘Etape quarry (company Colas)**

The large quarry of Raon l'Étape exploits the basaltic “trapp” representative of Devonian to Lower Carboniferous calc-alkaline volcanism in the northern Vosges in France. Thanks to its specific hardness and mechanical properties, the rock, crushed on site, is used as ballast or in asphalt mixes for the rail track construction. The trapp formation corresponds to a porphyritic basalt.

- **Overlying clays from the carbonate quarry (company Humens)**

Humens operates an open-pit limestone quarry at Pagny-sur-Meuse, where clay materials are processed. The quarrying activities are organized around four main working faces, each ranging from 15 to 20 meters in height. The darker, impure limestones, enriched with siliceous components (clays), overlie the limestone strata. These are not currently exploited but are instead used for the gradual backfilling of the site to facilitate reforestation ('reclamation') after mining.

The various aggregates involve therefore clays, carbonates, siliceous alluvial deposits, and basic rocks. They were selected based on 1) their expected physical properties, with sufficient contrasts to provide clear interfaces for the geophysical measurements, and 2) their porosity and permeability to allow for relevant fluid flow. Moreover, the base of the pit, down to 4 m, and the top of the fold are sealed by geomembranes (HDPE geomembrane) and a geobentonitic complex (NaBento – Geosynthetic Clay Liner - GCL), consisting of a sodium bentonite layer encapsulated between geotextiles, providing a low-permeability barrier.

Table 1. Aggregates and petrophysical properties that filled the various PEGGHy units.

Type and petrophysical properties of aggregates	Carbonates	Siliceous sands	Siliceous pebbles	Basaltic « trapp »	Clays
Volume	410 m^3	1 930 m^3	256 m^3	850 m^3	1 090 m^3
Granulometry	/	0/5 mm	20/80 mm	6.5/13 mm	0/5 mm
Aggregate Los Angeles abrasion test value	< 20	12-20	12-20	9-10	/
Aggregate micro-deval wear test	/	10-20	10-20	15-35	/
Porosity	/	/	30%	22%	20%
Hydraulic conductivity	/	1.6.10^{-4} m/s	/	/	10^{-8} m/s
Grain density	2.7	2.7	2.7	3.1	1.7
Aggregate density	/	1.6	/	2.4	/

3 Optical fiber instrumentation

Optical fiber measurement relies on the backscattering of a short (<10 ns) laser pulse injected into the fiber. The spatial distribution of the measured property, such as temperature, is determined using a highly accurate timing system that accounts for the velocity of light within the fiber.

Three types of optical fibers are installed: two at the bottom of the pit and the other near the surface. They all converge to an optical splice protection box which outputs the signals through a standard optical fiber cable equipped with various output ports so that different interrogator types can be used.

Sensitive optical fibers

Strain sensing and temperature sensing cables from our partner ANDRA (French national radioactive waste management agency) were installed at the bottom of the pit, enabling continuous recording of underground deformation and temperature associated to, e.g., water flow or mass loading at the surface. The pedagogical interest of such cables will be to provide real data to be compared to hydro-geomechanical simulations, showing students the significance of the different terms in the system of coupled equations and emphasizing numerical discretization issues.

Distributed acoustic sensing

A non-magnetic Distributed acoustic sensing (DAS) cable was supplied and installed by the SERCEL company at 15 cm depth within the platform. The Helically Wound Cable (HWC) has a very large cross-section (2 cm). It is a high-performance tool for monitoring both passive and active seismic vibrations, providing continuous records of the strain rate due to seismic waves propagating in the DAS cable direction (Zhan, 2020). Although challenges remain to make such data widely operable in the industry world, “DAS networks will inevitably complement classic seismic sensor deployment” (Nziengui-Bâ et al., 2023) for imaging the near-surface (Dou et al., 2017; Ajo-Franklin et al., 2019) in the future.

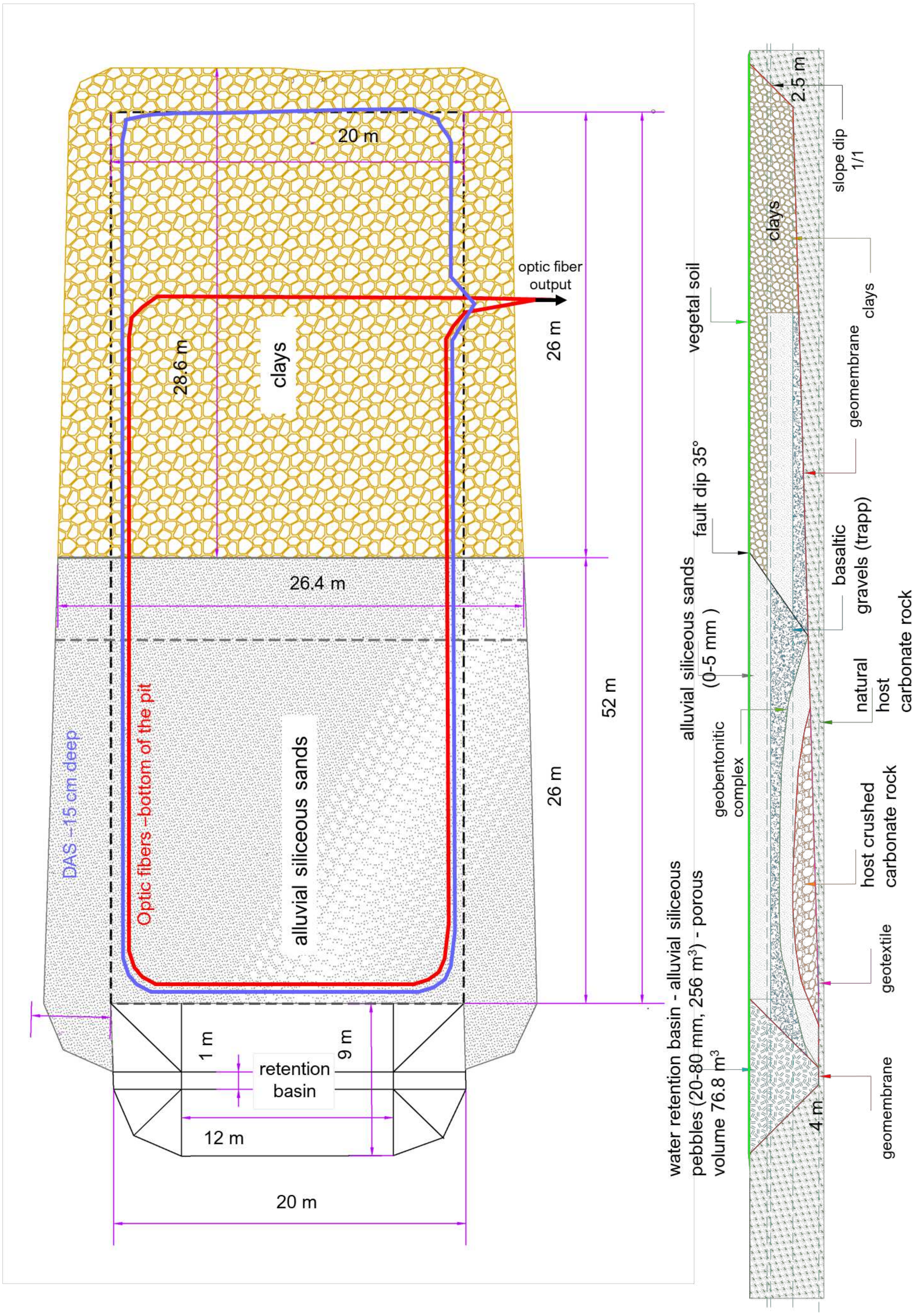

Figure 1. Technical drawings of the PEGGHy platform. Left: top view. Right: cross-section.

4 3D geomodelling – digital twin

Thanks to photogrammetric data acquired by drone, PEGGHy comes with a 3D digital twin. The dataset corresponds to 17 photogrammetric surveys acquired by Enerex SAS. Each survey was carried out at different times during the construction of the platform, so that it is possible to build a relevant, centimetric precision geomodel from the point clouds. Points were acquired using the European Terrestrial Reference System 1989 (EPSG 25832) coordinates and then turned into the RGF93 (EPSG 2154) coordinates to build the geomodel. This last coordinate system is 2D Cartesian along the East and North axes, and its unit is meter.

The 3D geomodeling is carried out using the Aspen-SKUA^{TM} geomodeler software. Several steps have been followed to build the triangulated surfaces of the model, with a 40 cm mesh resolution. The methodology relies on both the direct and indirect approaches described by Caumon et al. (2009) using the Discrete Smooth Interpolation (DSI) method (Mallet, 1992). The surfaces are explicit, meaning that their geometry is described by triangle meshes instead of iso-values of a 3D scalar field. The surfaces model the base of the platform, the physical interfaces between layers of various aggregates, and the faults (including the limit between the retention basin and the layers) (Figure 2).

The model is sealed, meaning that the connection of the surfaces (i.e., the topology) is properly controlled using border constraints. This allows to define volumes which corresponds to the different geological blocks of the platform. These volumes can be meshed with the desired resolution to perform numerical simulations of various phenomena such as seismic wave propagation, electrical potential field, fluid flow, and coupled hydro-geomechanical processes. Such simulations require physical property values. At this stage, only porosity, hydraulic conductivity and density values are known for a couple of blocks (Table 1). Other properties like elasticity coefficients, electrical resistivity or dielectric permittivity, could be estimated using inverse approaches.

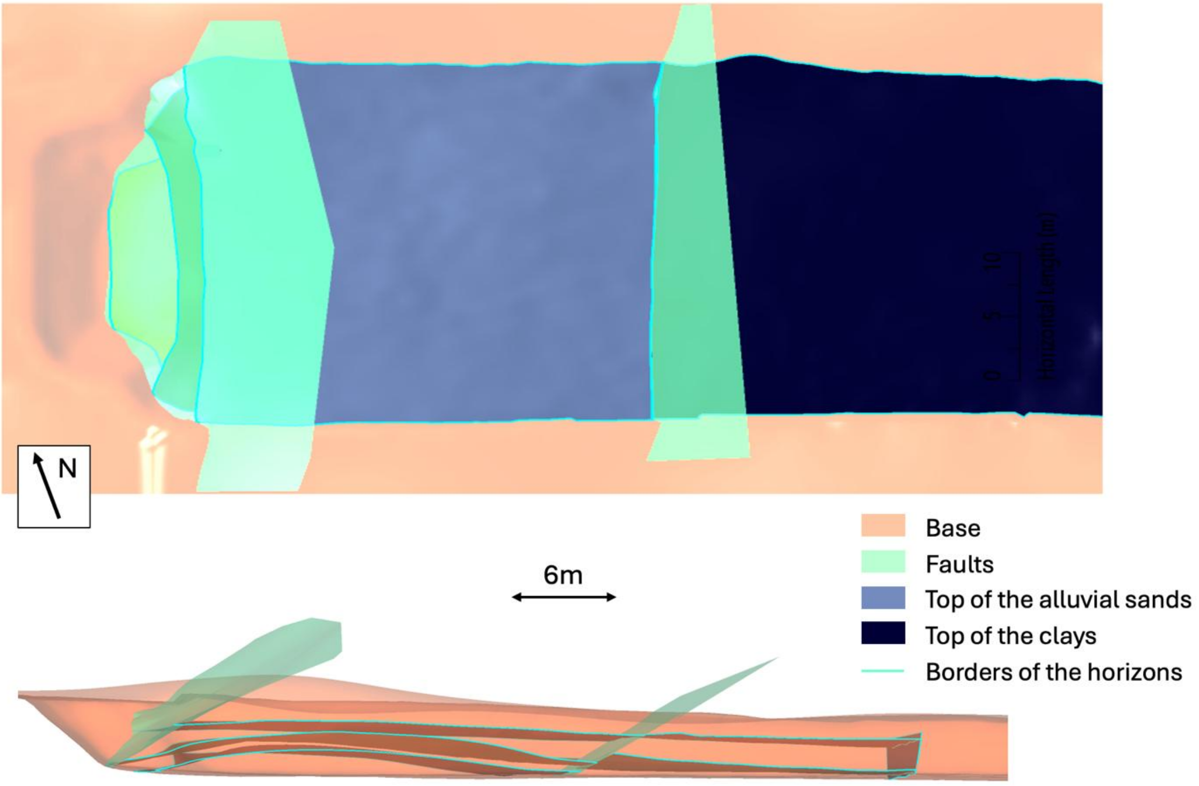

Figure 2. Top: map view of the PEGGHy digital twin. The topographic surface is hidden to exhibit the top of both the alluvial sands and the clays. Bottom: side view of the PEGGHy digital twin. All the horizons are shown except the topographic surface, the top of the shallower alluvial sands and the top of the clays. In the two parts of the figure, we let the fault surfaces extend above the topographic surface.

5 Some pedagogical perspectives for geotechnics and geophysics

A key educational objective in geotechnical engineering is to establish and manage the development of a "ground model", or geotechnical model as outlined by the Eurocode (EN 1997-2:2024. Eurocode 7 – Geotechnical design – Part 2: Ground properties. European Committee for Standardization, Brussels, 2024). This model represents both a conceptual and physical description of the subsurface conditions at a specific site. It plays a crucial role in understanding the geological and geotechnical characteristics of the ground, which directly affect the design and construction of structures.

To properly describe the geology of a site, a geotechnical model must integrate data from a variety of sources, including geological surveys, borehole logs, geophysical measurements, and laboratory tests. Geophysical methods, such as seismic refraction, ground-penetrating radar, and electrical resistivity surveys, offer valuable insights into the depth and nature of soil and rock layers beneath the surface. The geotechnical model not only reflects the vertical stratigraphy of the site but also incorporates lateral variations in geological formations. For example, the soil profile may shift from soft clay to dense sand at different points across the site. By considering these spatial variations, the model enables engineers to predict how the soil will behave under load, assess potential settlement, and identify risks such as liquefaction or shear failure during seismic events.

In addition to geological features, mechanical properties are essential. Before designing foundations for any structure, understanding them is mandatory for ensuring stability and safety. To do so, geotechnical subsurface measurements are conducted. They provide invaluable insights into the ground's behavior under load, enabling engineers to design foundations that are efficient, reliable and respecting the Eurocode standards.

Understanding the construction of 3D geological or geotechnical models is crucial for students. Constructing such models involves more than simply collecting data. It requires the ability to manage uncertainty, recognize and understand the various types of data, process various signals, and integrate diverse information sources. Borehole or punctual in-situ measurements provide detailed data, but they might not reflect broader regional trends. Conversely, and for example, electrical resistivity data offer a more extensive view of subsurface structures, but they are not as precise as point-based measurements. Training students to correlate and synthesize data of different types, resolutions and scales is essential to develop robust, reliable 3D models.

PEGGHy enables the deployment of standard (for pedagogical purposes) or more advanced (for innovative developments) geotechnical and geophysical instruments. Because it is a controlled geological environment, the features and models derived from the data can be quantitatively compared to the true underground, namely the digital twin of the platform. From a pedagogical point of view, this is extremely valuable, as it allows teachers to clearly point out limitations, uncertainties and pitfalls associated to geotechnical and geophysical characterization methods. In the following, we provide some examples of possible practical trainings and quantitative analysis of data enabled by PEGGHy.

5.1 Geotechnical in-situ measurements

Two key geotechnical field measurements are introduced to students to assess subsurface conditions, providing a solid background for understanding soil mechanical behavior and minimizing uncertainties related to composition, density, shear strength, and bearing capacity. These measurements help determine how the soil will respond to the weight of the structure and whether it has the necessary strength to support it without excessive settlement or failure.

Dynamic plate load test (PDL)

The lightweight deflectometer (*Plaque dynamique légère* -PDL- by Sol-Solution) is a field test designed to determine the dynamic deformation modulus (Evd) of subsoils, assess compaction quality and evaluate soil bearing capacity. Figure 3a presents a schematic of the device. Various empirical correlations (Prakashkumar & Rakesh, 2019) allow for the estimation of the static reloading deformation modulus (EV2) and the California Bearing Ratio (CBR).

Dynamic penetrometer test (Panda)

The lightweight variable energy version (Panda® by Sol-Solution) of the dynamic penetrometer test (DPT) is a portable device able to investigate the soil cone resistance down to a depth of 6 m. It is widely applied in France and other European countries, particularly for compaction control. The dynamic penetrometer log data can be used to estimate several geotechnical parameters, including: the California Bearing Ratio (CBR), the static reloading deformation modulus (EV2), the Standard Penetration Test N60, the static cone resistance Qc, the pressuremeter's limit pressure and modulus (pl and EM). This is possible using direct correlation equations (Benz-Navarrete et al., 2020). Figure 3b presents a schematic representation of the device.

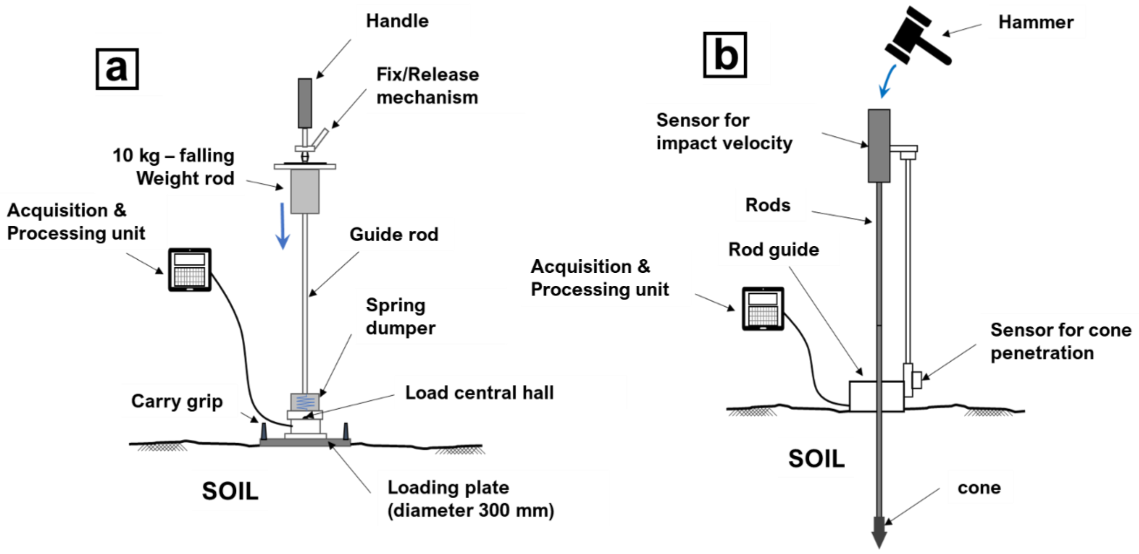

Figure 3. a) Lightweight deflectometer for the dynamic plate load test. b) Weight dynamic cone penetrometer.

Prospective learning activities in geotechnical engineering

As part of practical coursework in geotechnical engineering, students will be required to design an investigation program to establish a geotechnical model of the platform. They will define and conduct the necessary number of tests using both the Panda® and PDL devices. Additionally, complementary electrical and geomagnetic geophysical testing methods can be incorporated to verify the soil layers' continuity between tests locations and potentially identify subsurface anomalies.

Beyond its application in practical classes to demonstrate two widely known geotechnical in situ tests, advanced project-based learning activities are also planned. The intended learning outcome is to enhance students' ability to integrate local data—such as surface soil deformability from PDL and depth-dependent tip resistance from Panda tests—with the global inversion of geophysical surveys, to build the most accurate possible geotechnical design model.

Future developments could include scaled-down experimental devices for load testing of foundations elements (footing and pile), providing students with hands-on experience in geotechnical engineering.

5.2 Geophysical surveys

In geotechnical engineering, the use of geophysical methods is essential in supplementing traditional techniques by providing valuable data on subsurface conditions. Various geotechnical applications can be directly linked or compared with geophysical methods, each offering distinct advantages and working together to enhance site investigations.

While geotechnical methods deliver precise, direct, and reliable data on subsurface conditions, geophysical methods provide additional insights that contribute to a more thorough understanding of the site. As non-invasive techniques capable of covering larger areas more efficiently, geophysics is increasingly used alongside traditional geotechnical investigations to enhance site characterization, optimize foundation design, and ensure the safety and performance of engineering projects. By combining both approaches, engineers can minimize uncertainties, improve cost-efficiency, and make better-informed decisions throughout the design and construction processes.

Ground penetrating radar

Ground penetrating radar (GPR) is a non-invasive geophysical technique that uses high-frequency electromagnetic waves to investigate subsurface conditions. It provides a detailed view of the subsurface by detecting changes in the electrical properties (e.g., dielectric permittivity) of the underground materials. GPR is widely used for geotechnical investigations, archaeological surveys, environmental assessments, and other applications that require mapping near-surface features (e.g., Grandjean et al., 2000).

GPR can be easily implemented on top of PEGGHy. Figure 4 and 5 show a 600 MHz radargram obtained by ENSG students after basic processings such as redatuming, direct wave removal and gain application. The endpoints of the radargram are referenced in the RGF93 coordinate system so that the image can be introduced into the PEGGHy digital twin.

Figure 4 shows the western part of the digital twin, i.e., the base of the platform (pink) and the limit between the retention basin and the PEGGHy layers (green). In the radargram, a clear horizontal reflector is observed in the retention basin. Because water is accumulating in the basin thanks to the underlying impermeable geomembrane, this reflector can be interpreted as the water table. This illustrates the ability of GPR to image such a feature and to be used for mapping groundwater resources. The radargram also shows a dipping reflector, which corresponds to the limit between the retention basin and the PEGGHy layers. This reflector does not fit the true interface: it has an apparent dip, smaller than the true dip. This illustrates how radar sections can misposition and deform non-horizontal structures, similarly to post-stack sections in seismic reflection (e.g., Claerbout, 1985). When a wave velocity model is available, migrating these data allows to move reflectors to more accurate positions.

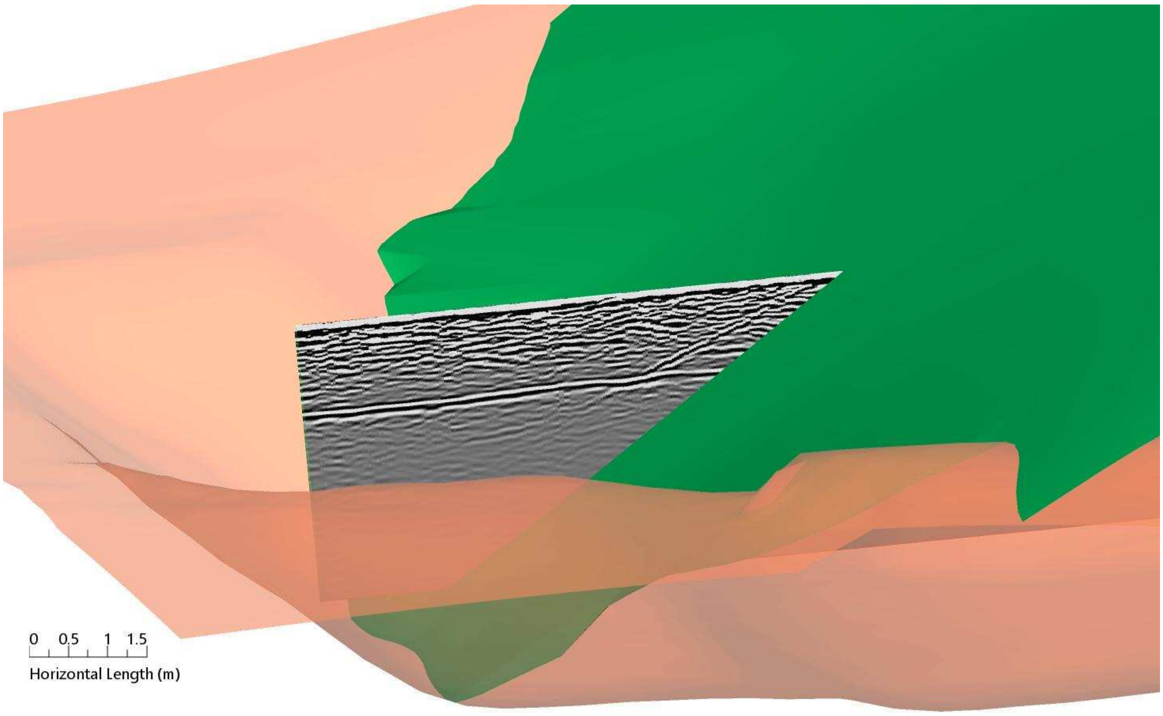

Figure 4. A GPR section in the western part of PEGGHy. The base of the platform is shown in pink and the limit between the retention basin and the PEGGHy layers is shown in green.

Figure 5 shows the same radargram as the one in Figure 4. The region of interest now is the other side of the limit between the retention basin and the layers. The horizon displayed in the figure is the top of the alluvial siliceous sands. This horizon is visible in the radargram, but it is shifted up and down by a couple of decimeters from the true horizon. Such a shift is due to the approximate surface topography of the radargram: instead of detailed 2D topographic data, a simple linear regression between the two endpoints of the radargram was used. As a consequence, the surface topography, even slight, maps into the horizons at depth. The effect is significant here because the shallowest, vegetal soil layer is very slow. When moving westward to the alluvial siliceous pebbles of the retention basin, the radar wave velocity suddenly increases, which pushes up the horizons in the radargram. These observations illustrate how radar wave velocity impacts the obtained GPR images. Instead of a homogenous velocity for converting time-to-depth, as used in our example (0.1 m/ns), a heterogeneous velocity model should be implemented to accurately image and position the horizons.

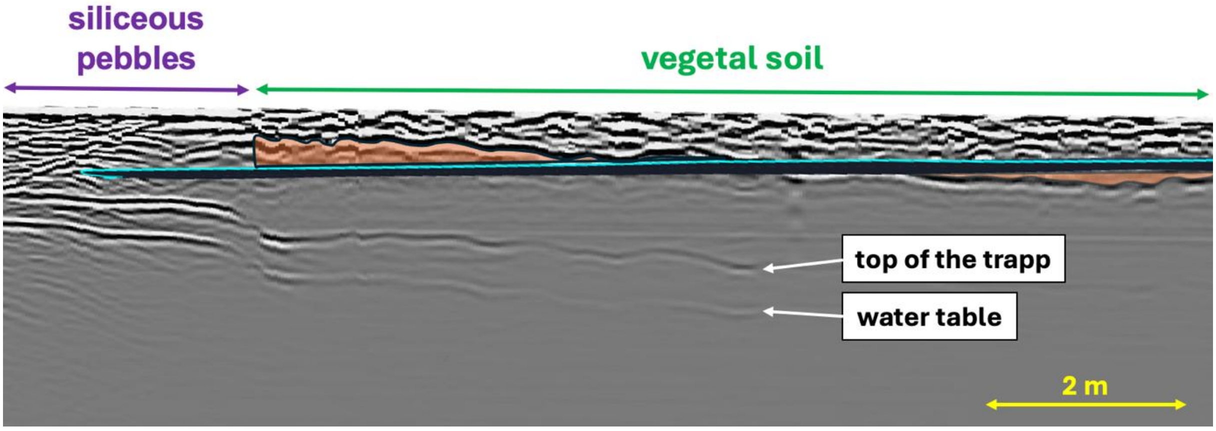

Figure 5. Same GPR section as in Figure 4, focused on the central part of the platform. The horizontal interfaces appear as highly deformed because of i) the approximated (i.e., flat) surface topography of the radargram and ii) the strong lateral velocity change when moving from the slow vegetal soil to the faster siliceous pebbles of the retention basin. To highlight the effect of the approximated topography, the shift between the top of the siliceous sands (whose borders are in cyan) and its corresponding reflector in the radargram is shown in shaded orange.

Electrical resistivity tomography

Electrical resistivity tomography (ERT) consists in measuring apparent resistivity data and inverting them to obtain the “true” resistivity values of the underground. This parameter refers to the property of a material to resist to the flow of an electrical current. In rocks, this parameter varies according to mineral composition, fluid content, porosity, fracture shapes, etc. Therefore, ERT is used for the identification of geological anomalies such as faults or cavities, mapping groundwater resources and locating contamination, and assessing soil properties for foundation design and geotechnical monitoring (e.g., Samouëlian et al., 2005; Cosenza et al., 2006).

Thanks to the vegetal soil layer, electrical resistivity surveys are easy to conduct on PEGGHy. Figure 6 shows both the apparent resistivity data acquired by ENSG students using a 48 electrode Wenner-Schlumberger array and the inversion result obtained using ResIPy (Blanchy et al., 2020). In addition to illustrating gradient descent optimization algorithms for deterministic inversion, such a field and processing work allows students to put in evidence the limited resolution of ERT by comparing the final geoelectrical image with the true underground (Figure 6). ResIPy, like any other ERT software, indeed provides a smooth image of the subsurface because of the incomplete and inaccurate data sampling (the inter-electrode distance is 1 m here) and because it applies model regularization to mitigate the non-uniqueness of the inverse problem (e.g., Friedel, 2003). Nevertheless, some structures can be recognized, such as the central fault between the two main compartments, the conductive vegetal soil layer on top more resistive materials in the western compartment, and the shape of the clay unit (including the vertical contact with the siliceous sands) in the eastern compartment. Deeper in the image, the resistivity values increase, which suggests that trapp and carbonate rocks are more resistive than sands. However, resistivity contrasts are weak there, because of i) possible weak contrasts between the involved layers and ii) the poor sensitivity at depth of the method.

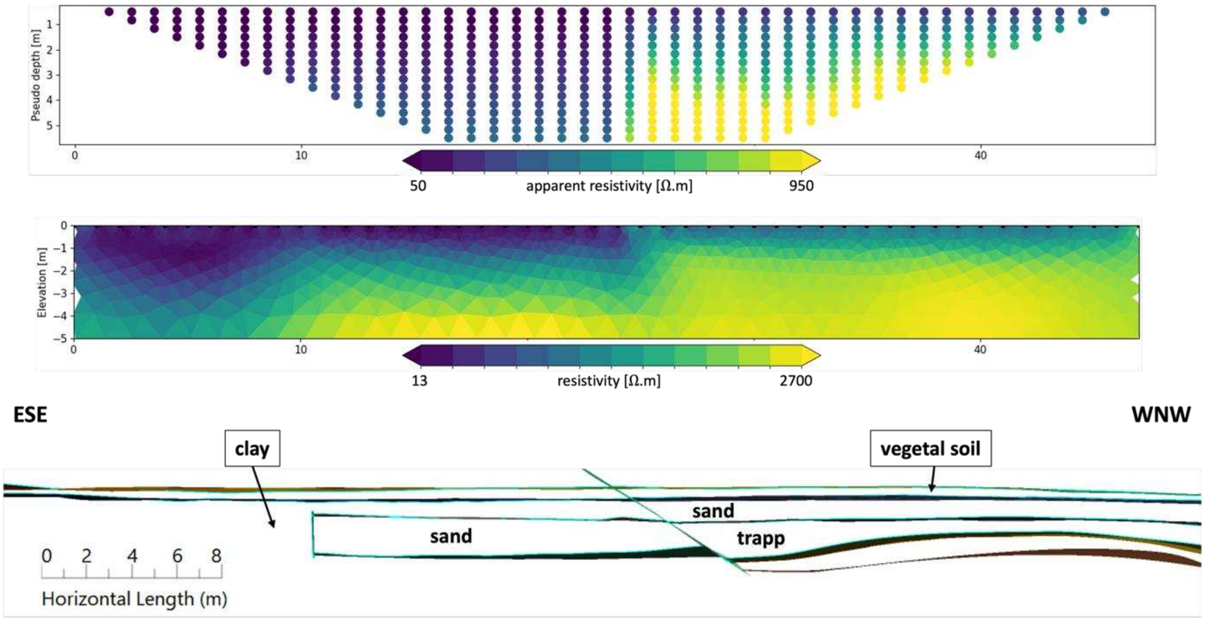

Figure 6. Top: apparent resistivity data from a Wenner-Schlumberger survey (48 electrodes, 1 m between two adjacent electrodes). Middle: geoelectrical section obtained from the inversion of the data. Bottom: section across the PEGGHy digital twin (for clarity, the base of the platform is not displayed).

Seismic refraction

Seismic methods rely on elastic waves propagating in the earth for imaging it at different scales. Among these methods, the seismic refraction approach is extensively used to study the near-surface. It relies on head waves, which travel along sub-horizontal interfaces and are easy to detect in seismic records because they arrive first. In geotechnical engineering, seismic refraction can be used to estimate the depth of the soil-bedrock interface (e.g., Abdelgowad et al., 2025) or geotechnical parameters like internal friction angle and Poisson's ratios (e.g., Pegah & Liu, 2016).

In summer 2024, ENSG students carried out a couple of three shotpoint seismic refraction profiles on top of PEGGHy. When inverting the data, both two-layer and three-layer models were tested, giving similar results for the depth of the shallowest discontinuity. Figure 7 shows the three-layer model obtained from a single profile. Comparing this model to the digital twin, one can interpret the shallowest discontinuity as the base of PEGGHy, meaning that all the inner layers of the platform are homogenized by the seismic method implemented here. Moreover, the investigation of the discrepancy between the true base and the one derived from all the seismic profiles in the ESE half of the platform reveals a Gaussian posterior uncertainty $\sigma = 22$ cm. This estimate is an interesting pedagogical input, as it points out the typical amount of layer thickness uncertainty in seismic refraction characterization of the near-surface. Furthermore, such a value allows us interpreting the WNW part of the discontinuity as the folded interface between the siliceous sands and the underlying crushed carbonate rocks.

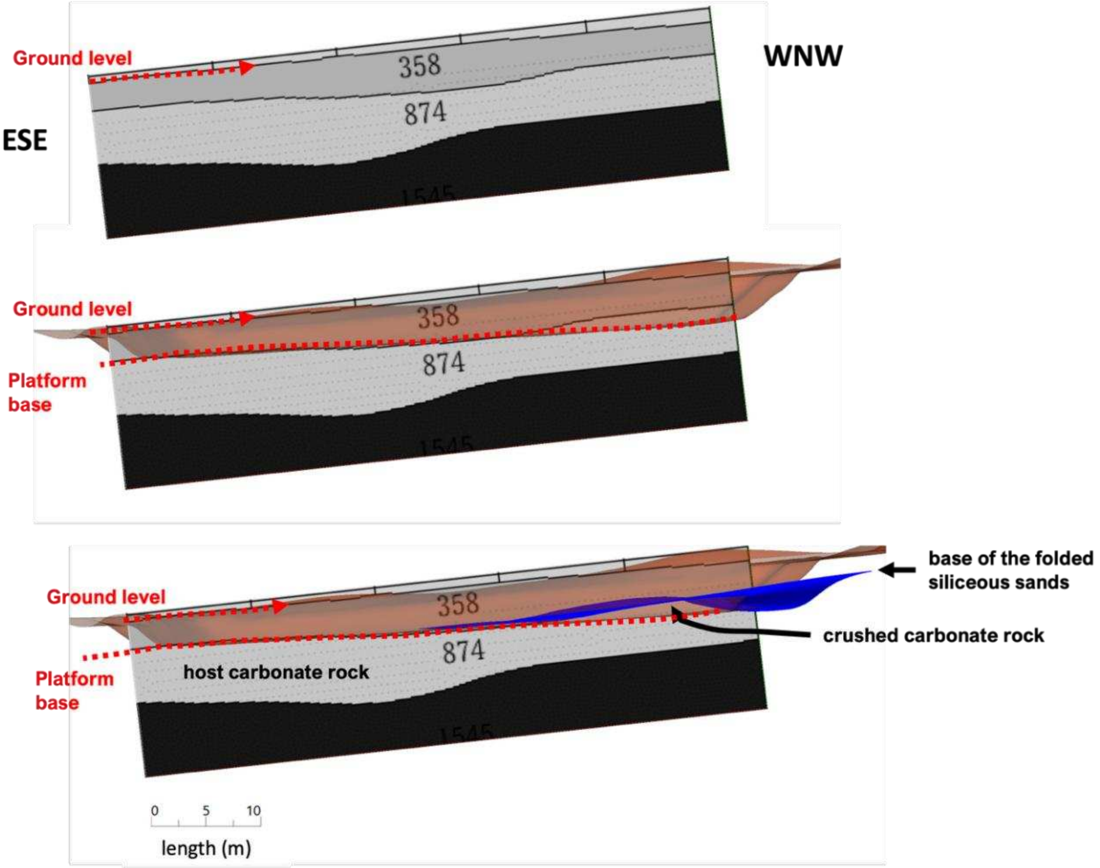

Figure 7. Result of a 2D seismic refraction tomography in PEGGHy. The obtained model shows three layers with different P-wave velocities. Comparing it to the digital twin, the shallowest discontinuity of the model is interpreted as the interface which separates the artificial units of the platform, especially the folded siliceous sands, from the underlying carbonate rocks.

6 Conclusion

PEGGHy enables enhancements of geo-engineering studies by providing near-real-scale practical experiences to students, allowing them to follow the full cycle of subsurface data acquisition and analysis using measurements from geotechnical and geophysical instruments. Each method can be taught independently, as presented in this paper, or it can be considered with other methods to build geological or geotechnical models from the integration of various data.

Because PEGGHy is a controlled geological environment, the features and models derived from the data can be quantitatively compared to the true underground, namely the 3D digital twin of the platform. From a pedagogical point of view, this is extremely valuable, as it allows teachers to clearly point out the inherent limitations (resolution, depth of investigation), uncertainties and pitfalls associated with all the geophysical and geotechnical characterization methods. Furthermore, the digital twin allows running numerical simulation codes and comparing their results to real data. This offers a unique opportunity to teach and test numerical schemes, discretization algorithms and monitoring methods.

Beyond the acquisition and data analysis examples presented in this paper, many other pedagogical uses can be considered, involving other processings (e.g., radargram migration, constrained inversions), settings (e.g., dipole-dipole ERT, lower frequency GPR) or methods (MASW, induced polarization, electromagnetic surveys, etc.). In addition, wellbores within the platform will open pedagogical applications in hydrogeology in the future.

PEGGHy is available to any academic training, research or development projects which require equipment or method testing based on the comparison of experimental measurements with features from the digital twin. The access to the platform and related data can be obtained by contacting the Graduate School of Geological Engineering or the authors.

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References

Abdelgowad, A.M., El-Haddad, A.E., Aglan, M.I., Hamed, A. (2025). Seismic refraction investigation of the shallow bedrock in New Qena City, Eastern Desert, Egypt. Scientific Reports, 15, 2646.

Ajo-Franklin, J.B., Dou, S., Lindsey, N.J., Monga, I., Tracy, C., Robertson, M., Rodriguez Tribaldos, V., Ulrich, C., Freifeld, B., Daley, T., Li, X. (2019). Distributed acoustic sensing using dark fiber for near-surface characterization and broadband seismic event detection. Scientific Reports, 9(1), pp. 1-14.

Benz-Navarrete, M.A., Breul, P., Bacconet, C., Moustan, P. (2020). The Panda®, variable energy lightweight dynamic cone penetrometer: a quick state of art. Engineering Geology.

Blanchy, G., Saneiyan, S., Boyd, J., McLachlan, P., Binley, A. (2020). ResIPy, an intuitive open-source software for complex geoelectrical inversion/modelling. Computers & Geosciences, 137, 104423.

Caumon, G., Collon, P., Le Carlier de Veslud, C., Viseur, S., Sausse, J. (2009). Surface based 3D modeling of geological structures. Mathematical Geosciences, 41, pp. 927-945.

Claerbout J.F. (1985). Imaging the earth's interior, Blackwell Scientific Publications, Oxford.

Cosenza, P., Marmet, E., Rejiba, F., Cui, Y.J., Tabbagh, A., Charlery, Y. (2006). Correlations between geotechnical and electrical data: a case study at Garchy in France. Journal of Applied Geophysics, 60, pp. 165-178.

Dou, S., Lindsey, N., Wagner, A.M., Daley, T.M., Freifeld, B., Robertson, M., Peterson, J., Ulrich, C., Martin, E.R., Ajo-Franklin, J.B. (2017). Distributed acoustic sensing for seismic monitoring of the near surface: a traffic-noise interferometry case study. Scientific Reports, 7(1), pp. 1-12.

Friedel, S. (2003). Resolution, stability and efficiency of resistivity tomography estimated from a generalized inverse approach. Geophysical Journal International, 153(2), pp. 305-316.

Grandjean, G., Gourry, J.C., Bitri, A. (2000). Evaluation of GPR techniques for civil-engineering applications: study on a test site. Journal of Applied Geophysics, 45, pp. 141-156.

Mallet, J.L. (1992). Discrete smooth interpolation in geometric modelling. Computer Aided Design, 24, pp. 178-191.

Nziengui-Bâ, D., Coutant, O., Moreau, L., Boué, P. (2023). Measuring the thickness and Young’s modulus of the ice pack with DAS, a test case on a frozen mountain lake. Geophysical Journal International, 233(2), pp. 1166-1177.

Pegah, E., Liu, H. (2016). Application of near-surface seismic refraction tomography and multichannel analysis of surface waves for geotechnical site characterizations: a case study. Engineering Geology, 208, pp. 100-113,

Prakashkumar, M., Rakesh, K. (2019). Correlative study of LWD, DCP and CBR for sub-grade. Journal of Engineering Trends and Technology, 67(9), pp. 2231-5381.

Samouëlian, A., Cousin, I., Tabbagh, A., Bruand, A., Richard, G. (2005). Electrical resistivity survey in soil science: a review. Soil & Tillage Research, 83, pp. 173-193.

Zhan, Z. (2020). Distributed acoustic sensing turns fiber-optic cables into sensitive seismic antennas. Seismological Research Letters, 91(1), pp. 1–15.

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Dr. Judith Sausse is a Professor at the Université de Lorraine within the GeoRessources Lab. She is currently serving as the Director of the National Graduate School of Geological Engineering (ENSG). She is a recognized expert in geosciences, specializing in reservoir geophysics, fractured reservoirs, geothermal exploration, and 3D geomodelling. Her research has led to 38 publications, and she is particularly noted for her contributions to geothermal energy systems, deep geothermal exploration, and petrophysics. Her teaching activities in geophysics cover gravimetric, magnetic, seismic, electrical, and electromagnetic methods, from both theoretical and applied perspectives. Her goal is to provide an in-depth understanding of these methods, focusing on subsurface techniques as well as the interpretation of well data in fractured reservoir domains. These courses are applied during field works at ENSG.

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Dr. Paul Cupillard is an Associate Professor at Université de Lorraine (UL) within the GeoRessources Laboratory. He obtained a M.Sc. in Geophysics from Strasbourg University (France) and a Ph.D. in Seismology from the Institut de Physique du Globe de Paris (IPGP, France). In 2008, he flew to California to work as a post-doc in the Berkeley Seismological Laboratory, UC Berkeley, for 30 months. After a second post-doc at IPGP, he obtained his current position at UL. A large part of his research is carried out in the frame of the RING-GoCAD consortium. His main research axes are i) the numerical simulation seismic wave propagation in complex geological media, ii) the homogenization of elastic properties for the seismic wave equation, iii) the inversion of seismic waveforms to retrieve geological parameters. On the teaching side, Dr. Cupillard give many classes at the National Graduate School of Geological Engineering, where he teaches the Finite Element method, Geomodelling, and Geophysics. In this last field, both theoretical and practical aspects are considered, including field works.

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Dr. Adel Abdallah is an Associate Professor of Geotechnical Engineering at the National Graduate School of Geological Engineering, Université de Lorraine, France, since 2000. He holds a Civil Engineering BEng from ENI Gabès, Tunisia (1993), a MSc in Civil and Mining Engineering (1995), and a PhD in Geotechnical Engineering (1999) from Lorraine National Polytechnical Institute in Nancy, France. His research focuses on coupled THM behaviour of natural, compacted and treated soils. He is particularly interested in numerical modelling and model parameter calibration, and in applications of machine learning and artificial intelligence in Geotechnical Engineering. He teaches soils mechanics at graduate and undergraduate levels, numerical modelling, geotechnical design and machine learning. He served as the Academic Dean of ENSG from 2012 to 2018.

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Dr. Yves Géraud is a Professor at Université de Lorraine, France. He obtained a PhD in geology and petrophysics from Université de Marseille in 1991 and then he worked as a research engineer at the applied geology laboratory of Université de Marseille. Between 1993 and 1995, he was Assistant Professor at ENS-Lyon. In 1995, he obtained an Assistant Professor permanent position at Université de Strasbourg. In 2012, he obtained his current position. He is the head of the teaching department « Géologie-Energies », a specialty of the National Graduate School of Geological Engineering devoted to the exploration of various energetic systems. His teachings are about structural geology, petrophysics, diagraphy, interpretation of geophysical data, field geology, energetic systems. He is also the head of the GreStock (for Reservoir geology and storage) team at GeoRessources Lab. It is a pluri-disciplinary team focuses on exploration of new energetic resources. His activity focuses on structural geology, petrophysics. He led several national and international research programs that yields 120 publications.

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Dr. Constantin Oltéan is an Associate Professor at the University of Lorraine. His teaching activities are mainly carried out at the Ecole Nationale Supérieure de Géologie of Nancy. They focus on engineering sciences and their applications in the geosciences (fluid mechanics, hydraulics, hydrogeology, modeling the behavior of aquifers, geothermal energy). As for his research activities, they are developed at the Georessources laboratory and focus particularly on: (i) the transfer of miscible fluids in porous media, taking into account phase heterogeneities and (ii) the physico-chemical interactions between the porous matrix and the liquid phase as part of a dissolution/precipitation reaction. In recent years, he has also focused on instabilities generated by non-Newtonian fluids in the presence or absence of surfactants and on flow in rough fractures. Whatever the topic, all his work is based on a strategy that integrates a triple approach, i.e. experimental, numerical and theoretical.

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Dr. Fabrice Golfier is a Professor at the National Graduate School of Geological Engineering, Université de Lorraine, France, where he teaches environmental engineering and hydrogeology courses. His research interests at the GeoRessources Laboratory focuses on coupled processes in porous media, including i) theoretical and numerical contributions to multi-scale modeling and ii) targeted applications in geosciences related with a sustainable use of subsurface resources (mineral deposit formation, hydrogen storage, nuclear waste deposit…) and environmental issues (groundwater contaminant transport, bioremediation of polluted sites).

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Dr. Olivier Cuisinier is a Professor of Geotechnical Engineering at the National Graduate School of Geological Engineering, Université de Lorraine, France, since 2008. He earned his PhD from Université de Lorraine in 2002 before joining the Laboratoire Central des Ponts et Chaussées (LCPC) as a Researcher, where he worked until 2008. That year, he transitioned to academia as an Associate Professor at Université de Lorraine, and in 2020, he was promoted to Professor of Geotechnical Engineering. Dr. Cuisinier's research focuses on the fundamental behavior of soils and the advanced laboratory characterization of fine-grained soils. With nearly 20 years of experience in soil mechanics, his expertise covers unsaturated expansive soils, naturally and artificially cemented soils, with a particular emphasis on their long-term behavior.

Beyond his research, Dr. Cuisinier actively contributes to the geotechnical community. Since 2024, he has been serving as the Chair of the Scientific Committee of the French Association for Soil Mechanics and Geotechnical Engineering.