

3D Ambient Noise Tomography for Preliminary High-Resolution Geological Surveys of Hydropower Dams – The Rhonergia Case Study (France)

Tomographie 3D par bruit ambiant pour une étude géologique préliminaire dans une zone de barrages hydroélectriques – Étude de cas Rhonergia (France)

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Abstract. 3D Ambient Noise Tomography (ANT) is a powerful, non-invasive method for imaging the shallow subsurface, offering a detailed understanding of geological structures relevant to geothermal and geological prospection. This paper presents the application of Sixense SISSTERRA solution in a project where more than 1,100 seismic sensors, including aquatic nodes, were deployed across three zones near the Rhône River. The objective was to delineate sedimentary structures, identify quaternary-tertiary transitions, and assess geotechnical risks. The use of underwater nodes in the Rhône enhanced spatial coverage and demonstrated the method's applicability in hydrologically complex areas. The data collected from ambient noise was processed to produce a 3D shear wave velocity (V_s) model, reaching depths up to 60 meters. This model enabled identification of lateral and vertical heterogeneities, highlighting areas of potential permeability or instability. Compared to traditional geophysical approaches, this technique delivers broader spatial coverage and higher-resolution imaging of subsurface features essential for early-stage geothermal site evaluation.

Résumé. La tomographie 3D par bruit ambiant (ANT) est une méthode puissante et non invasive pour imager la subsurface peu profonde, offrant une compréhension détaillée des structures géologiques pertinentes pour la prospection géothermique et géologique. Cet article présente l'application de la solution SISSTERRA de Sixense dans un projet où plus de 1 100 capteurs sismiques, incluant des capteurs aquatiques, ont été déployés sur trois zones situées à proximité du Rhône. L'objectif était de délimiter les structures sédimentaires, d'identifier les transitions quaternaire-tertiaire et d'évaluer les risques géotechniques. L'utilisation de capteurs sous-marins dans le Rhône a permis d'élargir la couverture spatiale et de démontrer l'applicabilité de la méthode dans des environnements hydrologiquement complexes. Les données issues du bruit ambiant ont été traitées pour produire un modèle 3D de vitesse d'ondes de cisaillement (V_s), atteignant des profondeurs allant jusqu'à 60 mètres. Ce modèle a permis d'identifier des hétérogénéités latérales et verticales, mettant en évidence des zones de perméabilité ou d'instabilité potentielles. Comparée aux approches géophysiques traditionnelles, cette solution offre une couverture spatiale plus large et une imagerie de plus haute résolution des structures du sous-sol, essentielles à l'évaluation préliminaire des sites géothermiques.

1 Context and Objectives

This project involves subsurface characterization along the Rhône River, a region with both complex sedimentary stratigraphy and hydrogeological dynamics. The primary goals were to:

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- Map quaternary alluvial formations and identify transitions to tertiary substratum,
- Assess the thickness and lateral variability of fine sediment layers,
- Identify fractured or weak zones indicating fluid flow paths or geotechnical hazards.

To achieve this, Sixense implemented 3D ANT using the Sissterra® solution, placing sensors on both land and riverbeds, including 4 nodes directly underwater, ensuring full spatial coverage.



Fig. 1. Sensor networks including underwater nodes in the Rhône River. Yellow dots : 391 nodes in the Clavières site, purple dots : 604 nodes in the Vernay site, blue dots : 209 nodes in the Buyatta site.

2 Technique and Measurements

Passive seismic tomography utilizes ambient noise to probe the subsurface [1, 2, 5, 7, 9, 10]. The method is based on cross-correlating the continuous seismic noise signals recorded by pairs of sensors. The noise is dominated by surface waves propagating in the shallow crust [6, 8]. The cross-correlations approximate the Green's function of the medium between the two sensors [3, 4, 11, 12], which is then used to derive surface wave dispersion curves. These curves are inverted in the 2–25 Hz frequency band to obtain 1D Vs profiles, integrated into a 3D Vs model.

For this project, over 1,100 sensors were deployed: 391 at Clavières, 604 at Vernay, and 209 at Buyatte. The recording period ranged from 168 to 192 hours per site. Underwater sensors in the Rhône were strategically placed to ensure data continuity across the river. The resulting dataset included more than 300,000 cross-correlation measurements.

The final 3D models provide a continuous representation of shear velocity in the first 60 meters of depth, offering key insights into subsurface structure, lithological transitions, and zones of potential permeability or mechanical weakness.

In this project, the average water depth in the Rhône river is approximately 5 meters. At high frequencies, when the wavelength becomes comparable to or smaller than twice the water depth, the recorded surface wave velocities near the surface may be slightly biased due to the presence of the water layer. This is because,

under such conditions, the measured group velocities can correspond to Scholte waves rather than Rayleigh waves [13, 14, 15]. Scholte waves, which propagate along the water-sediment interface, generally travel at slightly lower velocities than Rayleigh waves. However, this difference is typically within a few percent — on the same order of magnitude as the inversion error — and is thus negligible. Additionally, because the water depth remains relatively constant across the site, lateral variations in V_s are preserved and remain reliable.

3 Results and Interpretation

The 3D V_s models reveal the internal structure of the subsurface across the three study zones:

- Clavelières shows lateral heterogeneity with V_s up to 600 m/s, especially low V_s zones in the east and west.
- Vernay features higher V_s (up to 700 m/s) and more uniform layering below 10 m depth.
- Buyatte presents lower velocities overall (~450 m/s max), suggesting more recent or softer deposits.

V_{s30} values ranged from 250 to 510 m/s, in line with Eurocode 8 classifications. Zones with $V_s > 450$ m/s at target foundation depths suggest suitable conditions for infrastructure, while low- V_s zones may indicate risk-prone or hydraulically active layers.

Figures illustrating the sensor layout and velocity slices provide visual validation of the method's accuracy.

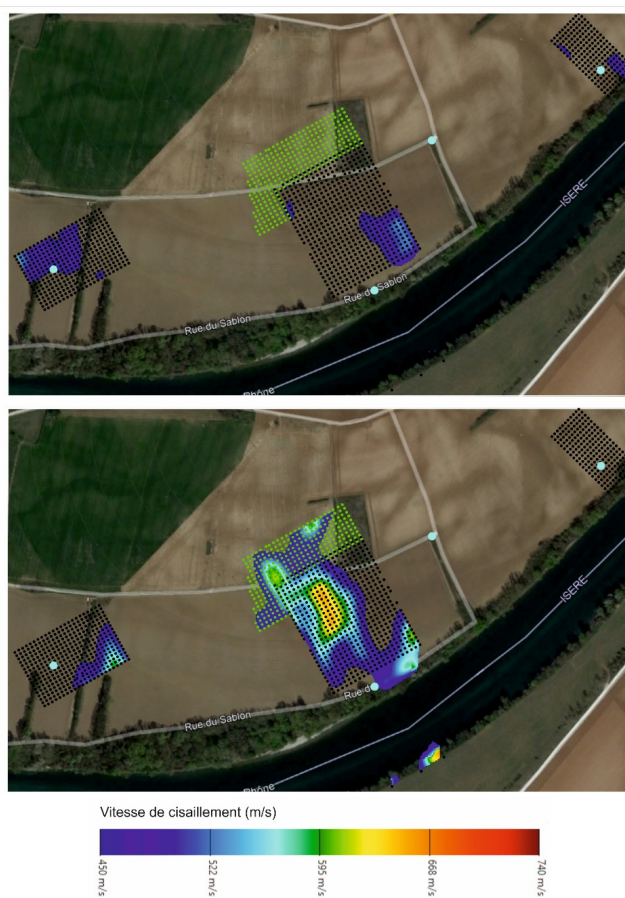


Fig. 2. 2D cross-sections of V_s at different depths (extracted from the 3D model) and focus on lower velocity zones – Centered on the dam foundation – Clavières site. Top figures: sections at the depth corresponding to the foundation level of the dam, bottom figures: sections at the depth corresponding to the foundation level of the power plant.

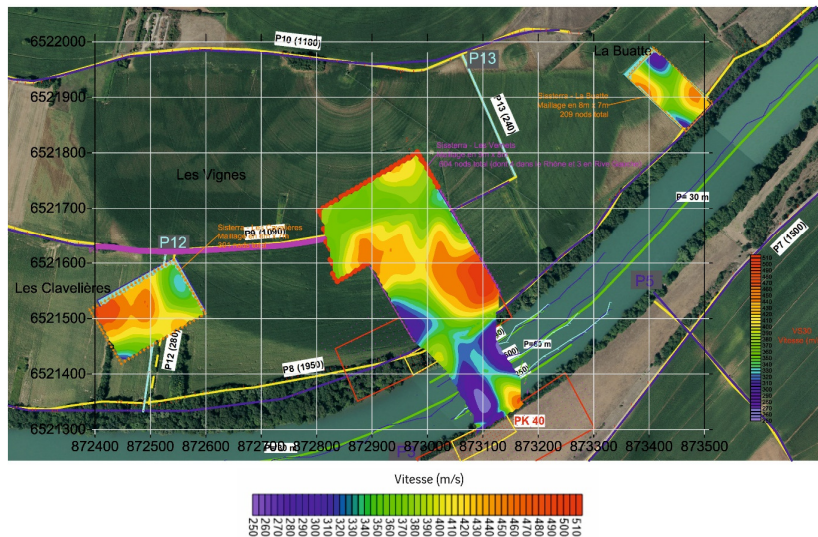


Fig. 3. Maps of VS30 (average shear velocity in the first 30m).

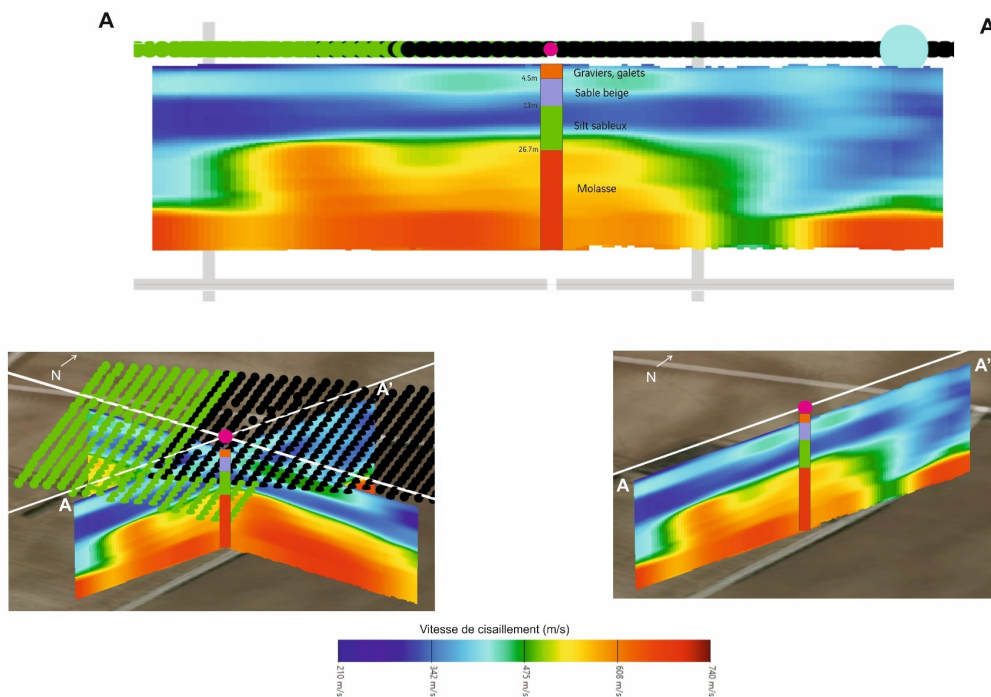


Fig. 4. Comparison of V_s values obtained by SISSTERRA at the intersection of a borehole in the area – Vernay site. The dots represent location of surface sensors.

4 Conclusion

This project has demonstrated the added value of 3D Ambient Noise Tomography (ANT) for geological and geothermal prospection in complex environments. Beyond generating high-resolution shear wave velocity models, the deployment strategy—including a set of seismic nodes placed directly in the Rhône River—showcased the method’s adaptability in mixed land–water settings. This ensured continuous lateral coverage, a key requirement for reliable interpretation of subsurface structures in hydrogeologically sensitive zones.

Thanks to its passive, non-intrusive nature, ANT provided spatially coherent data across varied terrain while maintaining minimal environmental impact. The presence of a shallow and relatively uniform water layer introduced only a limited and well-understood bias near the surface, without affecting the reliability of deeper velocity contrasts or lateral variations.

The resulting Vs models helped identify sedimentary facies transitions, areas of low material cohesion, and potential preferential water pathways—essential information for both **geothermal resource targeting** and **geotechnical risk assessment**.

This case confirms the relevance of 3D ANT as a practical, efficient solution for early-phase site characterization, especially in areas where traditional methods are constrained by surface conditions, access, or environmental sensitivity.

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