Acquiring Sustainable, Efficient High-Resolution Seismic Data for Geothermal Exploration in an Urban Environment

Drijkoningen, G.G.

DOI
10.3997/1365-2397.fb2022082

Publication date
2022

Document Version
Final published version

Published in
First Break

Acquiring sustainable, efficient high-resolution seismic data for geothermal exploration in an urban environment

Nick Tranter[1], Richard de Kunder[2], Ben Turner[3] and Guy Drijkoningen[4] present seismic acquisition technology for geothermal exploration within a challenging and restrictive urban environment.

Abstract

The overall conditions under which geophysical data are being acquired have changed over the past five years due to the global economy combined with an increased emphasis on low environmental impact sustainability and safety. For land seismic acquisition, minimizing land disturbance, reducing CO_2 emissions and increasing crew safety are key motivators to use innovations that drastically change conventional land seismic acquisition methods. One of the sources proven to do this is the eVibe developed by Seismic Mechatronics BV. They were recently contracted to undertake an urban seismic program utilizing their proprietary eVibe source in combination with Stryde Nodes. The seismic survey was acquired in one of the largest cities in the Netherlands, without the need for permits. Being able to minimize environmental impact, to reach a high safety standard and to acquire high-quality data in a noisy urban environment with the used technology made this project a success. This paper compares the results achieved by the Storm10 eVibe in combination with Stryde nodes to results previously obtained by an explosive survey. We show that the results are technically superior, with the eVibe and the Stryde Nodes proving far better suited to acquiring seismic data within this challenging and restrictive urban environment.

Introduction to the project

A single seismic profile was acquired in an urban area in the Netherlands parallel to an active railroad (Figure 1), to image to a depth of some 1500-2000 m for geothermal purposes. 1500 nodes were deployed along a 7.5 km line at 5 m spacing. The deployment of the Stryde receivers took three people just two days. The Seismic Mechatronics Storm10 eVibe was mounted on an electric Manitou MTE625 carrier (Figure 2). A 10 kW generator was used to power the source, which in future iterations will be replaced by a hybrid solution or battery-only pack. The source spacing along the 7.5 km profile was 10 m. Prior to beginning production, a test of sweep parameters was performed. Based on the sweep parameter tests, the following sweep was used for production: A (log-log) upsweep ranging from 2 to 100 Hz in P-wave mode, 24 sec sweep, -1dB per octave after correlation, with 1.02 sec start cosine tapers and a 0.3 sec cosine end taper (Figure 3). It was ascertained also during the sweep test that two sweeps were to be performed per source point.

Figure 1 Seismic line acquired in parallel to a railroad.

Figure 2 10kN Storm eVibe attached to electric Manitou MTE625.

Since the seismic profile ran through the city centre, a lot of traffic was expected both on the streets and the railroad. Therefore, to improve the safety of personnel and minimize external environmental noise in the data, it was decided to work during the night between ca. midnight and 5am. Despite this, there was still a lot of traffic both on the streets and on the railroad (many cargo trains passed the seismic profile). Consequently, an average daily productivity of ca. 200 sweeps was achieved. The eVibe source crew consisted of just two people, one being an observer travelling

[1] Stryde | [2] Seismic Mechatronics | [3] Dayboro Geophysical | [4] Delf University of Technology
* Corresponding author, E-mail: nick.tranter@strydefurther.com
DOI: 10.3997/1365-2397.fb2022082

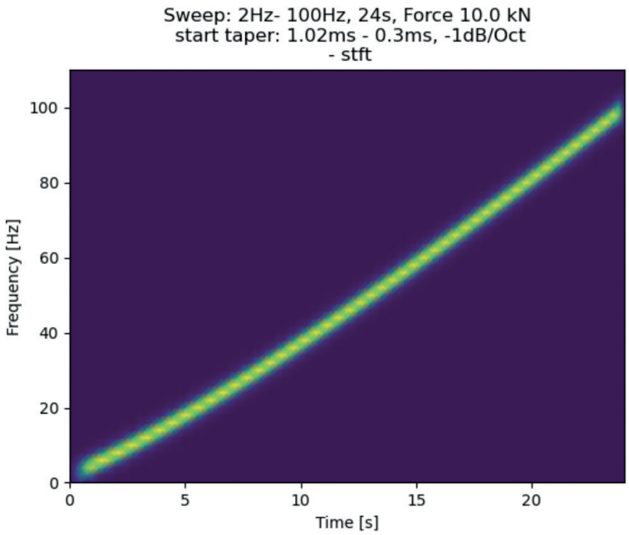

Figure 3 Sweep parameters, short-time Fourier transform.

in advance via an electric ATV and one being Storm10 eVibe operator. To conclude the survey, retrieval of the ca. 1500 nodes was completed in just one day by two people.

No equipment malfunctions were experienced during the acquisition program, and all operations went smoothly, with no reported HSSE incidents.

Moreover, due to the compact, quiet and electric seismic source and electric carrier, this seismic profile was shot without requiring any permits.

The receivers

Stryde Nodes are small, light, and affordable piezoelectric seismic receiver devices. These autonomous nodes are progressively replacing cable systems, freeing the operator from their bulkiness and access limitations, enabling urban surveys to become more achievable (Ourabah et al., 2022). These nodes come at a fraction of the size and cost of alternative nodal devices on the market today and can be discreetly buried, at various depths, or placed directly onto hard surfaces, with the ability to record seismic data continuously for at least 28 days in the field, (or more with calendar mode function).

The nimble nature of Stryde's miniature nodes (Figure 4) enables agile, fast, and low environmental impact seismic acquisition operations, opening new possibilities for urban exploration. The Stryde node weighs 150 g and is 129x41 mm in dimension, which

Figure 4 Stryde Node.

Figure 5 Stryde Node being deployed.

enabled the seismic crew members to carry and deploy more receiver devices by foot than ever before and eliminated the need for multiple deployment transportation vehicles on this project.

As a result of this, significant operational efficiencies, and reduced exposure to HSSE risk were demonstrated on this project with:

- 1500 nodes deployed in two days and retrieved in one just day by a team of three and two people, respectively.
- Only one compact (electric) vehicle was required for deployment and retrieval operations which had a significant impact on improving safety: road-related accidents are often the highest risk of seismic operations, especially in urban areas.

The nodes recorded at 1 ms sample rate for 10 hours/day, with very conservative GNSS settings, comprising a 60 minute GNSS wake-up and eight minute GNSS search time throughout the eight project days. Using these settings, approximately 60% of battery capacity was left after retrieval. The nodes were mostly buried in soil (Figure 5) in vegetation next to the railroad. The small modes were easily concealed, meaning that theft, a common issue in an urban environment, was not an issue.

In summary, the use of nodes on this acquisition enabled a magnitude of cost savings and operational efficiency gains, as well as reduced exposure to HSSE risk, and a significant reduction in environmental footprint and land disruption.

The seismic source

The eVibe is an electric seismic source that minimizes land disturbance due to the technology it adopts, being direct-drive electromagnetic motor technology (Figure 6). Direct-drive motor electromagnetic technology generates high-quality and repeatable acoustic signals for seismic acquisition. The direct-drive motors generate a linear or rotary movement without the use of a transmission or gearbox. Instead, these motors use permanent magnets and coil windings to generate frictionless movements. Therefore, the motors are highly efficient (>90% IEC4/5) and create reliable and high-quality seismic signals over a broadband frequency range (Noordlandt *et al.*, 2015). The technology enables compact sources to be built, while achieving a great depth of penetration. Moreover, in combination with electric carriers 'zero-carbon acquisition' is possible, fully eliminating any CO_2 emissions per vibrator point.

There are currently several eVibes commercially available, including the Lightning eVibe, the Synchro eVibe and the Storm10

Figure 6 10kN Storm eVibe.

eVibe. The Lightning eVibe is a P- and S-wave source offering 1.3 and 1.8 kN force, respectively, with a full-force sweep frequency of 8-400 Hz (capable of sweeping between 1-1000 Hz at lower force). Its sizes are 41x25x55 cm (=LxWxH in P-wave mode) and weights ca. 90 kg (Brodic et al. 2019).

The source technology creates possibilities to accurately (ca 10 microseconds) synchronize multiple sources, enabling a modular design. As a result, the Synchro eVibe is a P- and S-wave source offering 2.6 and 3.6 kN force, respectively, with a similar board bandwidth frequency range as the lightning. Its volume is ca. 41x50x55cm and its weight ca. 180 kg.

For this project, a 10kN eVibe was used, called the Storm10. This system is a P- and S-wave source with sizes of 50x81x90 cm and a weight of some 1000 kg with a full-force sweep frequency of 3.6-240 Hz (it is capable of sweeping between 2-450 Hz at lower force). The source can be attached to locally available carriers. In this case, an electric Manitou was used. The combination of the source plus carrier created a total weight of ca. 6700 kg with a width of ca. 180 cm.

Processing and data results

The data were processed through a state-of-the-art processing flow, adopting a pre-stack time-migration approach and utilizing advanced adaptive noise attenuation techniques. The challenging inner-city location of the seismic line resulted in the shot records being heavily contaminated with environmental noise. This noise, along with the normal expression of ground roll, were successfully attenuated and strong broadband reflectivity was able to be imaged.

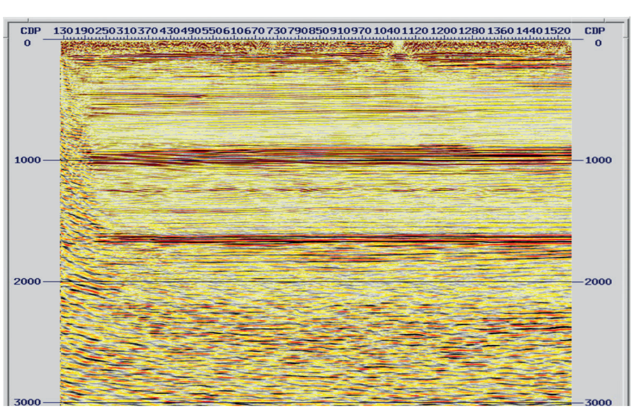

Figure 7 Part of the Pre-Stack-Time Migrated Stack.

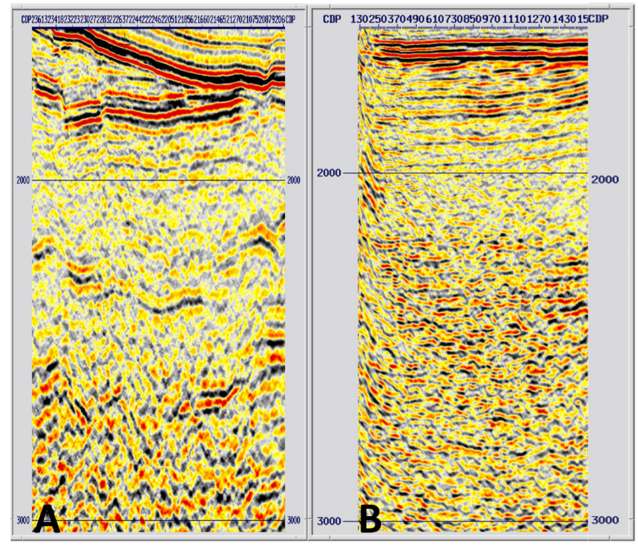

Figure 8 Comparison of the Pre-Stack-Time-Migrated Stack between (A) explosive data and (B) eVibe data til 1500ms.

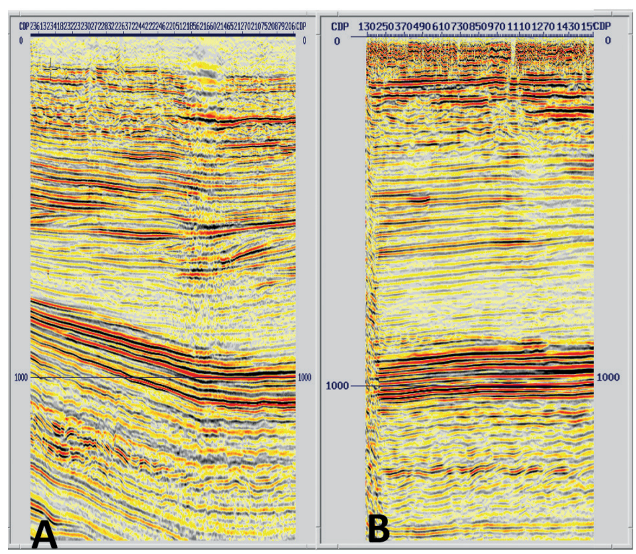

Figure 9 Comparison of the Pre-Stack-Time-Migrated Stack between (A) explosive data and (B) eVibe data till 500-2000 ms.

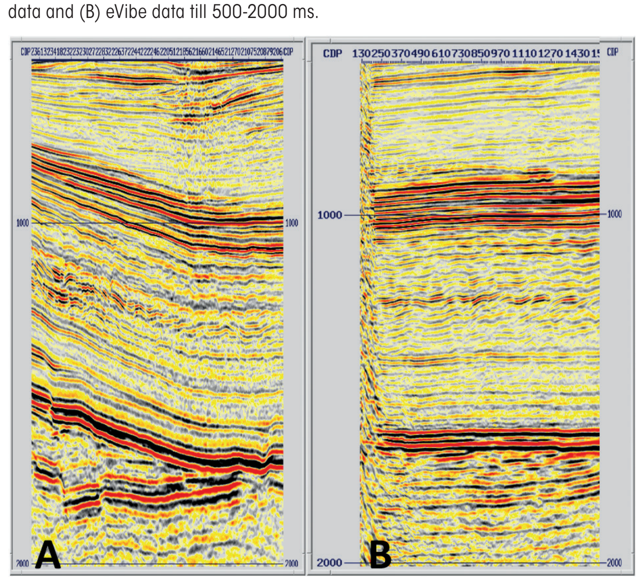

Figure 10 Comparison of the Pre-Stack-Time-Migrated Stack between (A) explosive data and (B) eVibe data till 1500-3000 ms.

The region containing the line comprises young, relatively soft sediments with a slow velocity trend ranging between 1200 to 2500 m/s. The main target of interest sits at approximately 1700-1900 ms TWT, which represents a depth of around 2 km. The processed data (Figure 7) exhibits excellent continuity and resolution down to the target depth, with the bandwidth of the sweep being largely retained through this entire section. Good reflectivity was also observed in the deeper section, although the limited spatial extent of the seismic line reduced the ability to properly image the deep section.

Perpendicular to the eVibe seismic profile, an explosive survey was acquired in 2021 which intersects the line. The explosive line intersects the eVibe line ca. 1.5 km from the start. This 2021 line was acquired using an expensive, high effort source and is considered to be of excellent quality. The 2021 explosive survey data was compared to the eVibe data as shown in Figures 8, 9 and 10. Based on the comparison, the eVibe data show higher resolution, better continuity and sharper imaging in both the near-surface as well as in the deeper subsurface.

Conclusions

A low environmental impact seismic survey for geothermal exploration was successfully acquired in a built-up, urban setting in the Netherlands. Recently developed seismic source and receiver technologies were used on the project, a Seismic Mechatronics Storm10 eVibe as seismic source and Stryde nodes for sensing and recording the data. The survey data set shows a significant image uplift compared to a recent overlapping 2021 explosive source survey.

These technologies demonstrated their ability to operate effectively in an urban environment, and minimized land disruption, risk, and environmental footprint by reducing the project duration and reducing the number of people and vehicles required to acquire the seismic data, when compared to conventional surveys.

With knowledge of the subsurface being critical in de-risking and advancing geothermal projects, the acquisition of this survey proves that more environmentally friendly technologies for seismic acquisition can successfully be deployed in urban environments. Moreover, they can produce better-quality images, when compared with conventional and more bulky methods, all at a more affordable price point and with less exposure to risk.

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