Abstract

Traditional seismological methods for the study of the Earth structure are based on the information that can be extracted from direct waves emitted by seismic sources such as earthquakes or explosions. Useful information about the Earth interior, that is not directly available, can also be contained in the ambient seismic noise sources. In the last 15 years the interest in these alternative methods has grown because they are particularly advantageous both for economic reasons and for overcoming some limitations of the traditional techniques. Indeed, they offer the opportunity for studying areas without a localized natural or artificial sources and can be used to assess the aseismic response of the subsurface. Correlations of ambient seismic noise traces are used to reconstruct the Earth impulse responses (Green's function) between two receivers as if a source was placed at one of them. From these information it is possible to reconstruct the elastic properties of the propagating medium in terms of spatial and temporal velocity variations of the seismic waves that travel through it, performing an *ambient noise tomography*. Velocity changes in the propagation medium are closely related to the physical mechanisms triggering natural or inducing earthquakes processes.
The aim of this thesis is the application of methods based on ambient noise analysis to the areas where industrial operations for the geo-resources exploration and exploitation take place. Any energy technologies can originate several environmental risks among which seismic risk, therefore application of efficient methods can enhance the ability to monitor and reduce seismic risks in specific areas.
This work was carried out within the three-year project *S4CE* (*Science For Clean Energy*) started in 2017 and funded by the European Union's Horizon 2020 research and innovation program (https://science4cleanenergy.eu/). This multi-disciplinary consortium aimed to improve the knowledge on the mechanisms concerning the sub-surface geo-energy operations in order to better monitor, quantify and reduce the environmental risks that may derive from it. The Università degli Studi di Salerno was one of the main partners and dealt with the management of data on microseismicity and the study of induced seismicity. In the 2019, the Università degli Studi di Salerno started to coordinate the three-year project *MATISSE* (*Methodologies for the AssessmenT of anthropogenic environmental hazard: Induced Seismicity by Sub-surface geo-resources Exploitation*) financed by the Italian Ministry of Education, University and Research, PRIN 2017. This thesis work is also part of this project, developed for detecting and quantifying the potential environmental hazards related to sub-surface geo-energy exploitation.
It was analysed the continuous noise recorded of two sites where different energy technologies was implemented for the exploitation of their geo-resources. This enabled testing of the methodology in different types of areas and industrial operations, and to assess differences and limitations. One of the study areas is the shale gas site of Wysin, which belongs to the Stara Kiszewa concession of Polish Oil and Gas Company (PGNiG) in Pomerania region of the northern Poland. In this region, the operations for the exploration and exploitation of the hydrocarbon was conducted in 2016 by using the hydro-fracturing technique. Cross-correlation analysis of two-month of continuous ambient seismic noise performed to investigate the propagation medium of Wysin site show coherent Rayleigh waves with a significant energy in the 1.5-2.0 Hz frequency band. The energetic signal propagates with an estimated velocity of about 400 m/s and can be considered reasonably time stable. The information obtained from the cross-correlation analysis were used to perform tomographic inversions with two different approch, to reconstruct 2-D surface waves velocity model of the medium. From the method using the surface wave arrival times picked on the stacked cross-correlation functions (FMST, Rowlinson and Sambridge, 2005), a fixed-frequency tomography in the narrow range 1.5-2.0 Hz was obtained allowing an investigation of the medium up to a maximum depth of about 70 m. Using a non-linear multiscale approach for data inversion (MANgOSTA, Cabrera-Pérez et al. 2020), the dispersion curves from cross-correlations were obtained by frequency-time analysis (FTAN). Tomographic images were retrieved for nine periods within the range 0.3-1.20 s, permitting to reach an investigation depth of about 150 m.

The second investigated site is one of the test fields of the European project S4CE, located in St. Gallen, northern Switzerland. This area was involved in a deep geothermal energy project for power production using water in aquifers at a depth of over 4 km. The project was realised in 2013 by the St. Gallen public utilities company (Sankt Galler Stadtwerke) in the proximity of an existing fault zone that offers greater permeability in favour of industrial activities. For this site, the cross-correlation analysis of three-month of continuous noise recording show a well identified coherent phases in the 0.5-0.9 Hz frequency band. The predominant signal results stable over time and propagates with an estimated velocity of about 1750 m/s. The tomographic inversion of traveltimes of surface waves derived from the stacked cross-correlation functions in the range 0.5-1.1 Hz explores the medium up to about 1.2 km.

When studying areas where anthropogenic activity related to the exploitation of subsoil resources can generate induced seismicity, it is essential to increase the detection of weak events to improve knowledge about the seismicity of the area and its related consequences. In seismology, when dealing with low signal-to-noise recordings, traditional event detection methods are often unable to recognise all the weak events hidden within the seismic noise. Machine learning techniques can be a useful tool to improve automatic event detection by recognising the similarity between events. In this study, the implementation of an automatic waveform-based detection system for recordings of the St. Gallen deep geothermal site is reported. Application of an automatic event detection using an unsupervised neural network algorithm was performed testing one-station low signal-to-noise recordings. The results are promising in discriminating events from noise and in clustering events by some of their main characteristics such as magnitude and location.