Introduction

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In the geophysics of oil exploration and reservoir studies, the seismic method is the most commonly used method to obtain a subsurface model. This method plays an increasingly important role in soil investigations for geotechnical, hydrogeological and site characterization studies regarding seismic hazard issues (Mari et al, 1999).

The surface seismic method involves:

- Seismic refraction (P or S waves), which provides a subsurface velocity model. This method, applied to P waves, is commonly used in the geotechnology field to identify changes in the position of the bedrock, as well as longitudinal changes of its physical state or that of its overburden (see AGAP's Guide Sismique réfraction, O. Magnin, Y. Bertrand, 2005).
- Seismic reflection, a type of two or three-dimensional subsurface ultrasound method, which initially provides an image of the acoustic impedance contrasts of the subsurface. Depending on the means implemented, an investigation can reach hundreds of meters to several thousand meters in depth. However, the method does not perform well in the first 20 to 50 meters.

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- Multiple Analysis of Surface Waves (MASW) which, by analyzing the Rayleigh or Love wave phase velocity in the frequency domain (scatter diagram), enables the calculation of the evolution of the shear wave velocity (V_S) within the first tens of meters of subsurface. This method is increasingly used in geotechnology in combination with the seismic refraction method to determine the shear modulus.

The vertical resolution of all surface geophysical methods decreases as a function of the depth investigated. To obtain a precise model of the deep subsoil's seismic parameters (propagation velocities of P waves (V_P) and S waves (V_S), and density), geophysicists use borehole data such as those provided by the well seismic and acoustic logging methods, in particular to carry out the tying and calibration at depth of surface measurements. In addition, processing provides both a model for the propagation velocities of waves (P and S waves) and also for density, such as the examples presented at the end of this introduction.

The examples presented in Figure 1 are extracted from 3D seismic data. Figure 1(a) is a near-surface example (Mari and Porel, 2007). The P velocity distribution was obtained by seismic refraction (tomography) for the very near surface (up to 30 m deep) and by seismic reflection (acoustic inversion) for the deep seismic horizons (20 to 120 m). This first example is the subject of the case study in Chapter 5. It should be noted that a similar approach could be made by combining the MASW method and the S-wave seismic method. Figures 1(b), 1(c) and 1(d) are derived from the processing of a seismic reflection survey carried out to map horizons down to 1,500 m deep (Mari and Yven, 2014). The distribution of velocity (V_P and V_S) and density were obtained by elastic inversion.

The examples presented in this introduction already make it possible to highlight the fact that surface and well seismic methods combined with acoustic methods can be used successfully to estimate mechanical modules (Poisson's ratio, shear modulus and Young's modulus...). The objective of this book is to illustrate that the processes applied in deep geophysical exploration, combining different seismic and logging methods, can be applied to certain geotechnical and hydrogeological surveys, and site characterization in the context of seismic hazard studies.

This book, which is composed of five chapters, aims to present some of these approaches and their applications for near surface surveys (<150 m):

- The first chapter provides an overview of the state-of-the-art technology in the geotechnical field regarding borehole measurements of subsoil shear wave velocity. It highlights the benefits of combining different methods: VSP-type well survey measurement with S_H waves, generally called downhole, transmission between boreholes generally called crosshole, and dipole type acoustic logging (PSSL).
- The second chapter is devoted to the well seismic method. It describes the implementation procedure, the means of acquisition (sources and sensors) used in the civil engineering field, the different types of waves that make up the well seismic recordings (volume waves and guided modes) and the processing sequences. For more information, see "Well seismic surveying" by J.L. Mari and F. Coppens, 2003, Editions Technip.

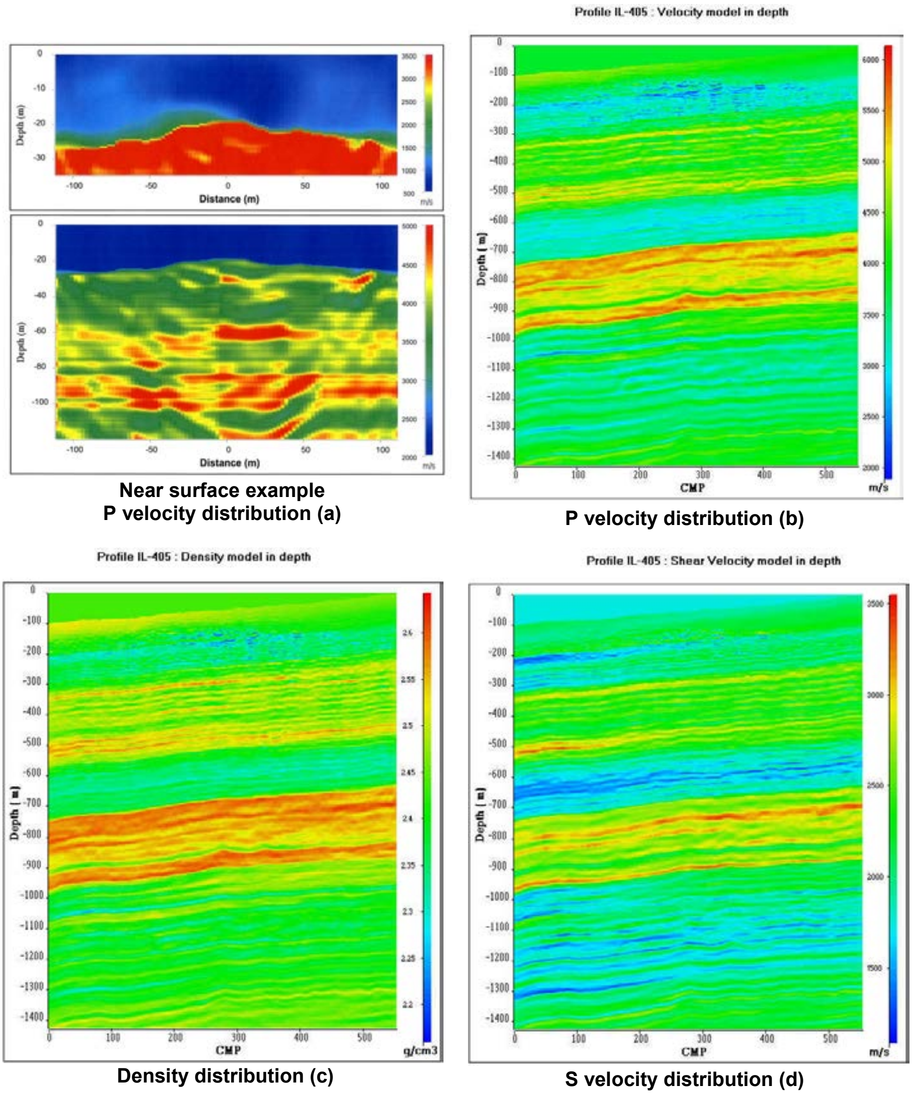

Figure 1 *Distributions of velocities and densities obtained by seismic surveying*
Near surface example (a), petroleum type example (b, c, d)

- The third chapter is about full waveform acoustic logging and its main applications in the civil engineering field. It briefly describes: the logging tools implemented (monopole or dipole), the different wave types that make up acoustic recordings, and the contribution of acoustic measurements to the description of geological formations (mechanical parameters). There is also a discussion on the contribution of Stoneley waves for the estimation of S velocities of formations and fractured zone detection. In addition, it shows how acoustic logging can be used to evaluate the quality of well cementation.

- The fourth chapter describes the benefits of combining measurements of formation velocities provided by VSP-type well tools and acoustic (sonic) tools. Based on a near surface example, it shows a tying method between sonic and check shots (VSP), which is used to obtain a time-depth relationship, tied to the seismic data and used for the conversion of logs into time and the calculation of synthetic seismograms.
- The fifth chapter is an integrated case study of a karstic limestone aquifer that is relatively close to the surface (20 to 130 m). We show how multi-scale description of the reservoir can be realized by integrating the information provided by different 3D-THR surface seismic methods, full waveform acoustic logging, VSP with hydrophones, borehole optical televiewer and flow measurement.

Note*: In the oil sector, the word 'well' is commonly used to mean borehole. This notion is not ideal for geotechnology usage, where boreholes are drilled for investigation and not production. In this document, we will therefore use the word 'well' for all descriptions relating to a transfer of technology from the oil world to geotechnology. However, 'borehole' will be used in relation to common geotechnical methods.*

References

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