# Seismic inversion for site investigation: How and where should we use it?

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**Introduction**

Commonly, the quantitative characterisation of marine sediments in the foundation and top-hole drilling zones (i.e., top tens to 1500 m) relies almost exclusively on extensive coring/cone penetrometer testing and stratigraphic correlation to seismic facies (e.g., Evans, 2011; Power et al., 2011; Vanneste et al., 2012). Meanwhile, the quantitative information stored in the amplitude, phase and frequency content of seismic reflection data, acquired as standard practice for all site investigations, remains little used. Instead, geophysical data is generally used for qualitative characterisation only, based solely on inference from a manual interpretation (e.g., Campbell, 1984).

In contrast, the hydrocarbon industry makes extensive use of the quantitative information stored within the complex seismic signal for reservoir characterisation, using a suite of different methods broadly termed seismic inversion (e.g., Wagner et al., 2012). While the application of similar seismic inversion techniques to the overburden has been broadly discussed for many years (e.g., Panda et al., 1992; Nauroy et al., 1998), there has been a significant recent upsurge in interest (see, Vardy et al., 2017). Within industry, the shift towards more geologically complex and deeper water sites, combined with the global economic climate, has driven a requirement for more cost-effective site characterization to reduce both over-design (i.e., cost) and risk. While, in academia, a coincidental explosion in the ready availability of high-performance computing (e.g., cloud computing) and a boom in funding for machine learning problems have made the large-scale application of computationally intensive inversion techniques across a range of subjects practically feasible.

However, despite the increase in interest and availability of appropriate expertise, software, and hardware, the widespread uptake of seismic inversion for quantitative characterization of the overburden has been slow. At least in part, this can be attributed to uncertainties surrounding how best to make use of seismic inversion within an already complex, multi-disciplinary site investigation work flow. In this paper, we attempt to provide some illustrative answers to some of the most critical questions using a range of different data sets and inversion methods. We show examples of using seismic inversion to derive results appropriate for different stages of the site investigation workflow, including: large-scale mapping of relative property changes and subsurface complexity, appropriate for early-phase site investigation; and detailed derivation of complex geotechnical properties, suitable for late-phase site investigation.

While not an exhaustive exploration of the various potential applications, these examples capture some ways in which seismic inversion could be utilized to answer various questions throughout the development cycle.

**Example Results – Late-Phase Application**

If seismic inversion is to be a useful tool late in the site investigation workflow, it has to be possible to robustly derive advanced soil properties information of direct use in the engineering-design and installation phases (i.e., geotechnical properties). While robustly obtaining absolute values of bulk sediment properties (e.g., bulk density or porosity) from seismic inversion is eminently possible with an appropriate parameterization and suitable calibration data (e.g., Vardy, 2015), deriving geotechnical properties is a much more challenging problem (Vardy et al., 2017).

Nauroy et al. (1998) attempted to empirically quantify the relationship between several geophysical properties and geotechnical measurements using data from three sites in the Mediterranean. Their analysis demonstrated a loose relationship between the seismic and geotechnical parameters, however the trends were highly non-linear, had a large amount of scatter and showed clustering between the different sites. An alternative method to capture the complex relationship between these parameters is to use machine learning techniques, such as Artificial Neural Networks, to perform a multi-attribute regression between multiple seismic properties and one or more geotechnical property of interest. We demonstrate the effective application of this technique to derive synthetic cone penetrometer tip resistance and sleeve friction profiles from typical site investigation geophysical data in a complex, previously glaciated site (see, Figure 1)

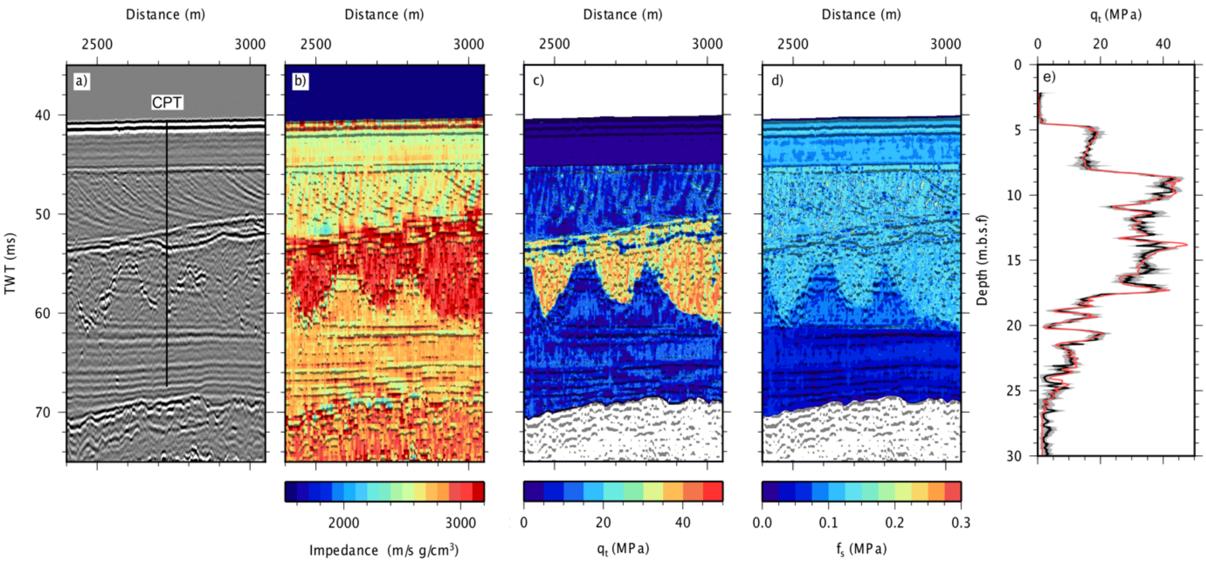


**Figure 1: Results of applying acoustic impedance inversion and multi-attribute regression using an Artificial Neural Network to a section of typical site investigation data. Panel (a) shows a section of single channel boomer data. Panel (b) shows the corresponding acoustic impedance profile obtained using the acoustic impedance algorithm of Vardy (2015). Panels (c) and (d) show the results of using an Artificial Neural Network trained at adjacent CPT locations to predict tip resistance and sleeve friction profiles based on the seismic reflection profile and inversion results. Panel (e) compares the predicted tip resistance results (black line) with the measured CPT tip resistance profile (red line) at the location shown in panel (a), which was not one the training locations.**

## Conclusion

We provide some illustrative answers to questions surrounding the practical usage of seismic inversion for marine site investigation, demonstrating the effective derivation of useful properties using a range of typical marine geophysical data sets.

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