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InterPACIFIC project: Comparison of invasive and non-invasive methods for seismic site characterization. Part I: Intra-comparison of surface wave methods

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ABSTRACT

The main scope of the InterPACIFIC (Intercomparison of methods for site parameter and velocity profile characterization) project is to assess the reliability of in-hole and surface-wave methods, used for estimating shear wave velocity. Three test-sites with different subsurface conditions were chosen: a soft soil, a stiff soil and a rock outcrop. This paper reports the surface-wave methods results. Specifically 14 teams of expert users analysed the same experimental surface-wave datasets, consisting of both passive and active data. Each team adopted their own strategy to retrieve the dispersion curve and the shear-wave velocity profile at each site. Despite different approaches, the dispersion curves are quite in agreement with each other. Conversely, the shear-wave velocity profiles show a certain variability that increases in correspondence of major stratigraphic interfaces. This larger variability is mainly due to non-uniqueness of the solution and lateral variability. As expected, the observed variability in $V_{S,30}$ estimates is small, as solution non-uniqueness plays a limited role.

1. Introduction

The shear wave velocity (V_S) model plays a key role in seismic site response analysis, since shear wave propagation controls ground motion amplification [1,2]. Seismic building codes, such as Eurocode 8 [3] and NERHP Provisions [4], use $V_{S,30}$ (i.e. the time-averaged velocity in the topmost 30 m) to define soil classes for simplified assessment of seismic site response. Also, most modern GMPEs (Ground Motion Prediction Equations) used in seismic hazard evaluation consider $V_{S,30}$ as a parameter to bin sites on the basis of expected site amplification [5–8]. An accurate study of the seismic response can be derived from numerical methods, and in this case, a 1D, 2D or 3D distribution of V_S is required.

The V_S model can be retrieved either with invasive tests, such as cross-hole or down-hole tests, or non-invasive methods, such as surface-wave methods or refraction tests. Invasive methods are

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generally considered more reliable than non-invasive methods because they are based on the interpretation of local measurements of shear-wave traveltimes, providing generally a good resolution as a function of depth. However, invasive methods require the drilling of at least one borehole, making them quite expensive for obtaining deep information. Hence, they are usually adopted only in projects of relevant importance. Non-invasive techniques provide cost efficient alternatives. Specifically, methods based on the analysis of surface wave propagation are increasingly more and more popular [9–14]. Surface-wave methods require usually little efforts for field acquisition. However, they require processing and inversion of the experimental data that are much more computationally intensive than those required for invasive methods. While the processing of the dispersion curve is quite robust as discussed by Cornou et al. [15] and Cox et al. [16], the surface-wave inversion problem, used to obtain a V_S profile, is highly non-linear and affected by solution non-uniqueness. These factors can induce interpretation ambiguities on the final V_S model [17–25]. In literature, different techniques for both dispersion processing, (e.g., [26–31]) and inversion (e.g., [21,32–39]) of the experimental data have been proposed. These techniques can be considered reliable if expert users apply them. However, because of the low cost and time effectiveness of surface wave methods and the availability of "black-box" software, non-expert users are increasingly adopting these methods. Uncorrected interpretation of the surface-wave data may lead to large errors in the resulting V_S profile, generating sometimes a lack of confidence in non-invasive methods.

In the past, several projects were carried out to improve the overall state-of-practice in surface-wave methods, like the NERIES-JRA4 European project (NEtwork of Research Infrastructures for European Seismology) [9]. In 2006, an international blind test [15] was conducted, but this was mainly focused on ambient vibration array recordings. Asten et al. [40] report a blind comparison of five independent interpretations of ambient vibrations, at two sites in basins on the North Anatolian Fault, Turkey. Tran and Hiltunen [41] compared results obtained by 10 independent teams who analysed the same experimental dataset collected with linear arrays recording active-source data and ambient vibrations. Kim et al. [42] report on a local blind test with independent measurements and analysis of surface wave data at a site with shallow bedrock in which variability of borehole methods was also investigated. Cox et al. [16] proposed a blind test, in which the participants analysed the same dataset of both passive and active surface-wave records, aimed at assessing the uncertainty/variability in both dispersion and V_S estimations. Unfortunately, the lack of in-hole tests did not allow an independent assessment of accuracy of the prediction at the site considered in this blind test.

In this context, the InterPACIFIC (Intercomparison of methods for site parameter and velocity profile characterization) project is aimed at comparing the main techniques for surface-wave methods (intra-method comparisons), as well as comparing non-invasive techniques with invasive ones (inter-method comparisons) at three European sites with different subsurface conditions. In this paper we report only the intra-method comparison among the surface-wave results in order to evaluate the reliability of surface-wave methods. The inter-methods comparison between surface-wave methods and in-hole techniques is discussed in a companion paper [43]. This intra-method comparison of surface-wave results will help us to improve the understanding of those issues that could impact the reliability of site characterization results.

The three test-sites selected within the interPACIFIC project (Fig. 1) are characterized by different subsurface conditions: a site with soft soil overlying rock (Mirandola); a site with stiff soil extending to significant depths (Grenoble); a rock outcrop site (Cadarache). The Mirandola site is located in Italy near the epicentral area of the 2012 Emilia seismic sequence [44], and consists of approximately 100 m of soft alluvial soil overlying rock. The Grenoble site is situated in an Alpine valley in France, and consists of very deep, stiff alluvial deposits from about 500–800 m [45]. The Cadarache site, also in France, is a rock outcrop site. At all of the sites, invasive (in-hole) measurements were performed (at least two boreholes were available) while surface-wave data were acquired in the vicinity of the boreholes.

Fourteen expert teams (engineers, geologists and seismologists) from different institutions/companies (see Table 1), were invited to take part at a blind test in surface wave analysis. The same experimental non-invasive datasets were provided to all of the teams. Each team was allowed to use all or part of the data provided. Very little supplemental information was provided about the sites.

Each team was free to adopt the strategy and the procedure they considered the best to estimate a V_S profile for the site, with no specific requirements on investigation depth and resolution. In order to take into account the issue of non-uniqueness of the solution, the teams were required to provide both their best estimate of the V_S profile and an associated uncertainty bound (or a range of possible solutions). Nevertheless, a comparison of the uncertainty bounds is not straightforward, as the non-uniqueness is quantified with several different strategies by the analysts.

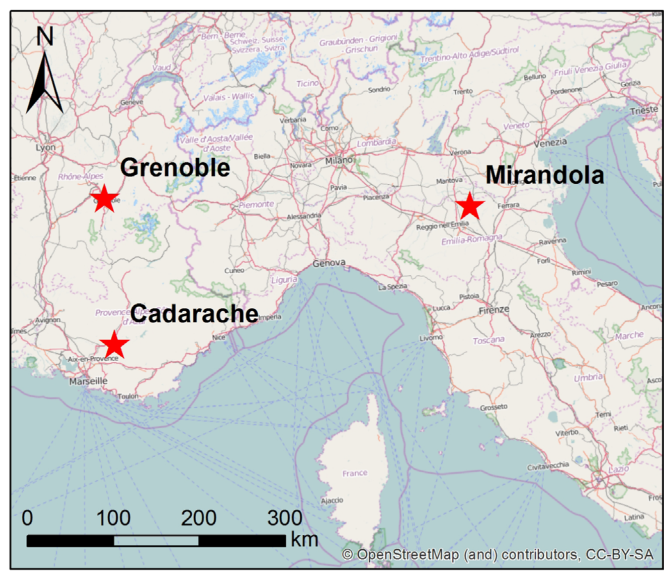

Fig. 1. Localization of the three sites: Mirandola in Italy, Grenoble and Cadarache in France.

Table 1
List of teams participating in the surface-wave analysis blind exercise.

ID	Label	Participants	Country
1	MU	Michael Asten, Monash University	Australia
2	CE	Diego Mercerat, CEREMA	France
3	IST1	Cécile Cornou, ISTerre	France
4	UT	Brady Cox, University of Texas	USA
5	INGV	Giuseppe Di Giulio, INGV	Italy
6	BFO	Thomas Forbriger, Black Forest Observatory	Germany
7	Geom	Koichi Hayashi, Geometrics	USA
8	IST2	Bertrand Guillier, ISTerre	France
9	KU	Shinichi Matsushima, Kyoto University	Japan
10	TT	Hiroaki Yamanaka, Tokyo Institute of Technology	Japan
11	GV	Antony Martin, Geovision	USA
12	SED	Valerio Poggi, Stefano Maranò, Jan Burjanek, Clotaire Michel, SED-ETHZ	Switzerland
13	PU	Matthias Ohrnberger, Potsdam University	Germany
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