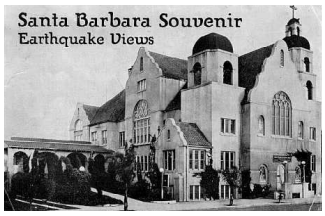

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EVALUATING ADVANTAGES AND DISADVANTAGES OF DIFFERENT METHODS OF VELOCITY PROFILE CHARACTERIZATION: PRESENTATION OF AN UPCOMING PROJECT

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ABSTRACT

The determination of seismic wave propagation velocities is essential to study the effects of site, not only for determining soil classes or Vs30 values, but also to determine the whole velocity profile, from the surface down to the bedrock. Several method exist to provide velocity profiles, including invasive and non-invasive approaches (Boore, 2006). When they are applied on the same site, they not always produce the same results. We wish to launch a project to compare these different method and better assess their complementarity. This project is open to teams that wish participate.

In order to determine Vs profile, the borehole techniques (mainly crossholes and downholes) are often considered as reference methods. They have however the following drawbacks: they are costly and invasive, investigate a relatively small volume of material compared to the wavelength of seismic waves, use high frequency range for measurements (typically 500 Hz to 1 kHz for cross-hole techniques) than those involved during earthquakes (typically 0.5 to 20 Hz).

Conversely, non-invasive active or passive surface wave methods are inexpensive, allow for the characterization of a representative volume of material and involve frequency range of interest in engineering seismology. However, their implementation, especially the inversion step, does not yet have standardized procedure that often involves misinterpretation (Cornou et al., 2006).

Moreover, recent comparison between borehole and non-invasive measurements have shown striking results at stiff sites: velocity values estimated with surface wave techniques are smaller than those derived from boreholes measurements (Moos, 2008; Renalier and Endrun, 2009). We therefore wish to launch a project to better assess the complementarity of invasive and noninvasive methods and the associated uncertainties.

We wish to launch a project to better assess the complementarity of invasive and noninvasive methods and the associated uncertainties. This project could also lead to the drafting of standardized implementation of noninvasive methods. This project would implement the various methods (invasive / non-invasive) at two or more sites and be widely open to teams wishing to test their methods. The results will be discussed during several workshops in an iterative process.

1. KNOWING THE SEISMIC WAVES VELOCITY PROFILES (AND VS30…): A NECESSITY.

As part of the evaluation of local seismic hazard (and more generally the estimation of geo-mechanical quality of the soil), it is essential to be able to determine the wave velocity (mainly shear waves) of soils. This determination concerns Vs30 parameter (used in most design practices and regulation rules), but also the complete Vs profile (not only within the first 30 meters below the surface, but down to the bedrock).

Two main groups of methods exist for determining these profiles:

- invasive methods,
- non-invasive methods.

2. THE CURRENT LEADERSHIP OF INVASIVE METHODS

Invasive methods (in particular the “crosshole” method) are often deemed as the most reliable methods, sometimes even considered by some experts as the only methods of interest. Nevertheless, the main disadvantage of invasive methods is that they are... invasive. The crosshole method needs the drilling of at least two boreholes (and usually 3 to 4). As a result, these methods are also relatively expensive to implement. The downhole method (often done in addition to the cross-holes) can be implemented with a single borehole, as well as the method "PS Suspension Logger” (figure 1) which presents an interesting alternative.

Moreover, these methods are using frequencies that are higher than the seismologic signals involved in an earthquake. Corollary, a crosshole only investigates a limited volume of soil (few meters) and does not cover the full scale of a facility or building.

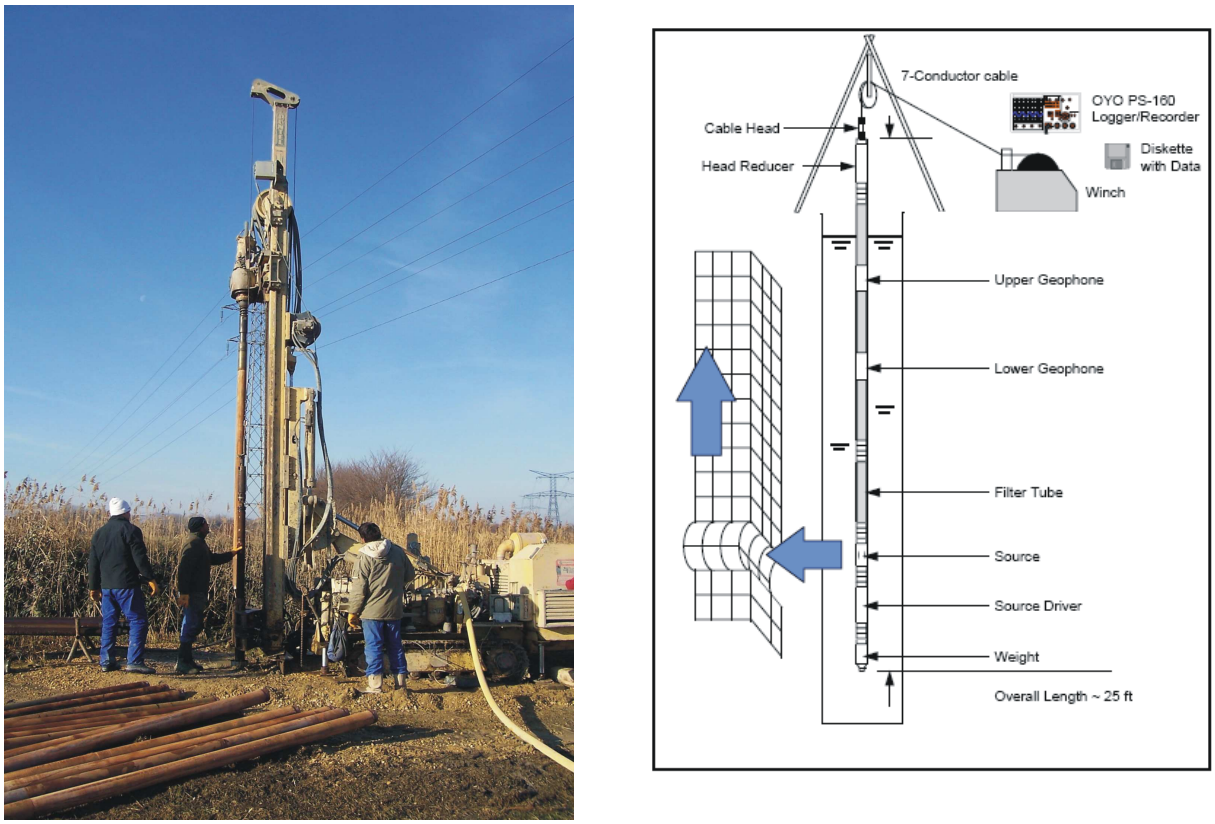

Figure 1 : On the left: drilling operation in preparation to a crosshole measurement, on the right: “PS Suspension Logger” : a diagraphic tool that can generate both P and S waves in the soils (source : www.geovision.com).

3. NON-INAVASIVE METHOD, A REAL ALTERNATIVE?

Many non-invasive methods exist. Most of them use the phenomena of surface waves dispersion. This dispersion is analyzed and translated into dispersion curve. This curve is then inverted to obtain a velocity profile. The surface waves used are either those of the ambient vibration (passive methods) or waves generated with an active source, e.g. a hammer striking to ground (active methods). Various receiver geometric configurations are implemented. Note for example the MASW (figure 2) method (usually active) where the receivers are placed along a line and array methods (SPAC, fk ...), in general passive, where the sensors (velocimeters) are positioned according to more complex geometric figures.

The non-invasive methods have, at first glance, the benefits that address the disadvantages of invasive procedures:

- they are not invasive
- they are inexpensive to implement
- they implement the frequencies and wavelengths closer to seismic phenomena.

Nevertheless, there is currently no "standard" for the application of these methods, the construction of dispersion curve and the inversion itself. Like the beginnings of the use of the method H / V, the errors of implementation are still numerous.

The result of the inversion is not necessarily unique. In order to obtain reliable velocity profiles, we need integrate the results of different methods (eg MASW + f-k or SPAC), varying inversion approaches, and therefore having a certain practice of these methods. Given previous results quite confusing, these methods are still far from being accepted in the communities that need Vs profiles or Vs30 parameter in their input data.

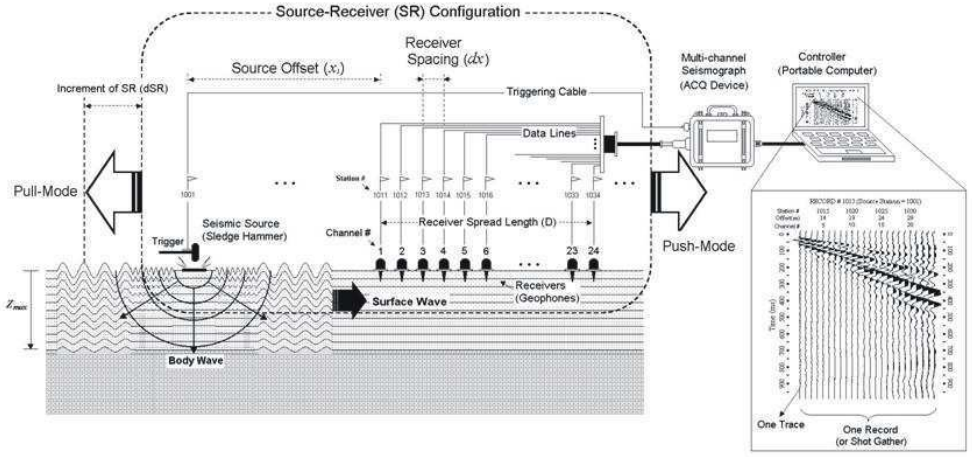

Figure 2 : MASW measurement principle (source : www.masw.com)

4. COMPARISON OF INVASIVE AND NONINVASIVE METHODS

Some works allowed comparing the two sets of methods (figure 3 to 5). Some general trends emerge:

- the discrepancies between the various invasive methods are smaller than the discrepancies between the various non-invasive methods,
- the discrepancies between invasive and noninvasive methods can be large on whole velocity profile, these differences are less large for the Vs30 parameter, but these differences remain significant
- on stiff soil and rock sites, the velocity values produced by the invasive methods are generally higher to those produced by non-invasive methods.

It is essential to understand and quantify these features.

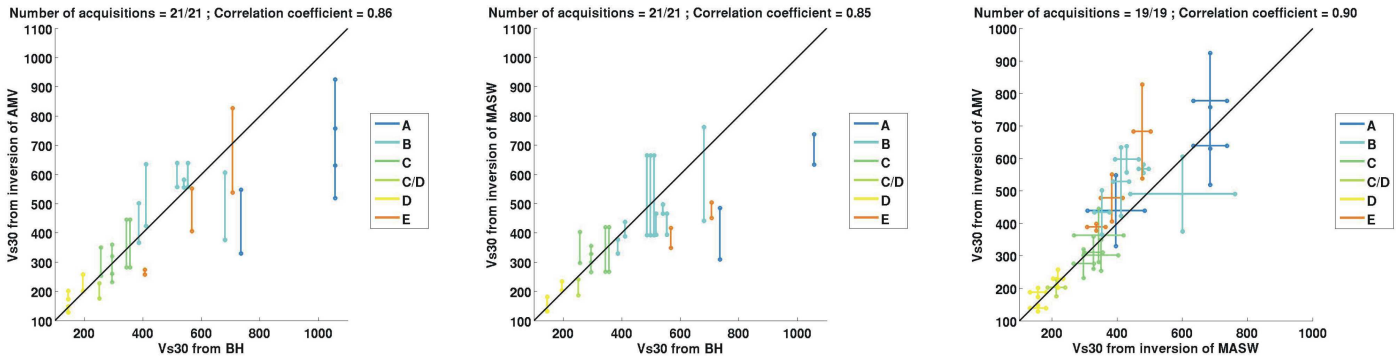

Figure 3: Correlation beetween different methods (BH : invasive methods, MASW : active non invasive method, AMV : passive

ambient vibration methods using arrays (Renalier F. and Endrun B, 2009)

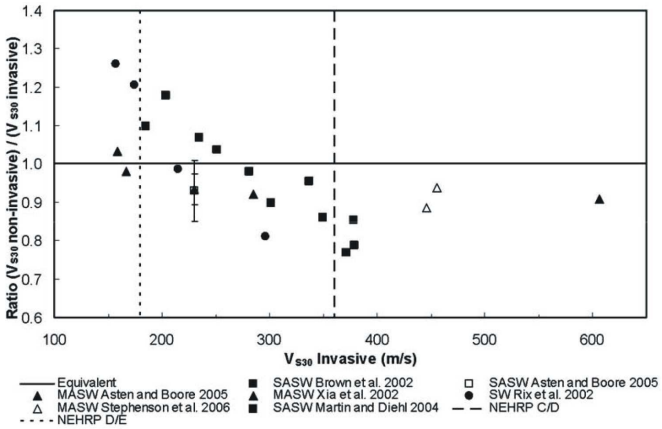

Figure 4: Correlation between invasive and non-invasive methods (Moos, 2008)

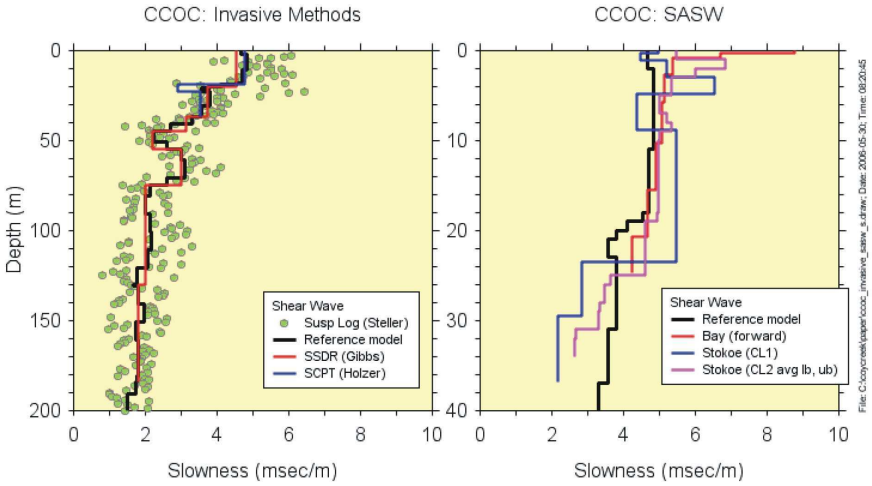

Figure 5: Result comparison between several invasive methods (left) and non-invasive methods (right). Reference = crosshole (invasive). (Boore, 2006)

5. UPCOMING PROJECT HIGHLIGHTS

We want to launch a project:

- to better evaluate the differences intra-methods and inter-methods discrepancies, and more generally the uncertainties
- to better understand the cause of these discrepancies
- to provide the basis for a "good practice guide" for the use of non-invasive methods
- where appropriate, to promote the use of non-invasive methods.

The project “road map” is summarized hereafter:

1. Choice of 2 to 3 different test-sites (eg. soil soft, stiff soils, rock). This choice would be carried out during a kickoff meeting involving all the interested participants.
2. Realization of boreholes on these sites and realization of invasive methods (cross-hole, downhole, PS suspension logger). If possible, perform crosshole measurements in the same boreholes by two different contractors.
3. Measurements with non-invasive methods on the same sites (with no restrictions on the type of method).
4. Discussion on the results through workshops, sharing of data recorded to achieve "cross-interpretation".

Other remarks:

- The workshops logistics (accommodation...) would be supported by the "SIGMA project", as well as the borehole realization and invasive measurements. Boreholes remain open to teams who would like to make borehole measurements.
- Non-invasive measurements would be undertaken by all teams potentially interested in participating in this project (universities, research institutes, etc.).
- The selected sites will likely be chosen in France or in neighboring countries (eg. Germany, Italy, Switzerland…).
- In addition to the 2-3 major test sites, we can consider other sites where invasive measurements have already been made and where some complementary non-invasive measurements could be perform (on a wider country area).
- The entire project would be done over a period of two years.
- All of these items are still open for discussion: please make your comments and suggestions!

The project will be co-supported by the SIGMA project (involving "Electricité de France", the "Commissariat à l'Energie Atomique et aux Energies Alternatives", AREVA and ENEL Energy).

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