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RPM ANALYSIS AND ADVANCED JOINT PROCESSING OF A SED (SWISS SEISMOLOGICAL SERVICE) DATASET

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In the framework of a series of site characterizations at some of the seismic monitoring stations operated by the Swiss Seismological Service (Schweizerischer ErdbebenDienst - SED), we recently tested an innovative method for the Holistic acquisition and analysis of the Surface waves (HS) recorded by means of a single 3-component (3C) geophone (Fig. 1).

The method originally consisted in the joint analysis of the group-velocity spectra of both the vertical (Z) and radial (R) component, together with the RVSR (Radial-to-Vertical Spectral Ratio) (Dal Moro *et al.*, 2014, 2015).

We here introduce a further *object* aimed at both further constraining the inversion process (thus obtaining a even more robust shear-wave velocity profile), and at providing to the structural engineers quantitative information regarding the occurrence of Rayleigh-wave prograde motion, recently identified as potential critical factor for the stability of a structure in case of earthquake (Trifunac, 2009).

An effective way to analyze the actual Rayleigh-wave Particle Motion (RPM), was introduced in Dal Moro *et al.* (2017) through the computation, frequency by frequency, of the correlation coefficient between the radial component and the Hilbert transform of the vertical component of Rayleigh waves. The obtained RPM frequency curve (or frequency-offset surface in case of multi-offset data) provides quantitative information about the actual Rayleigh-wave motion (the RPM curve equals to +1 in case of perfectly retrograde motion and to -1 in case of prograde motion) and can be used to further constraining a joint inversion procedure (Dal Moro, 2017; Dal Moro and Puzzilli, 2017).

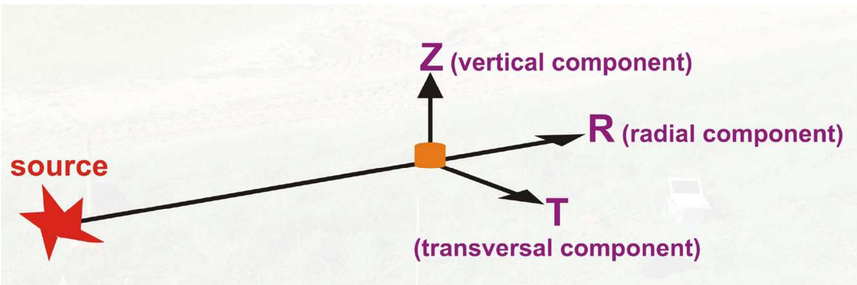

Fig. 1 - Multi-component (single-offset) acquisition of the active data used to implement the HS approach adopted for the present work.

For the present work, together with the group-velocity spectra of the Z and R components and the RPM and RVSR curves, we also considered the transversal (T) component (i.e. Love waves) and the Horizontal-to-Vertical Spectral Ratio (HVSR).

The adopted nomenclature (ZVF, RVF and THF - Dal Moro, 2014) refers to the vertical and radial components obtained while adopting a Vertical Force (VF) and to the transversal component obtained by means of a Horizontal Force (HF) [wooden beam].

The HS approach represents an improvement of the classical MFA (Multiple Filter Analysis - Dziewonski *et al.*, 1969) or FTAN (Frequency-Time ANalaysis - Natale *et al.*, 2004) methods (which, incidentally, are fundamentally identical).

Differently than the MFA/FTAN approach, HS relies on the analysis of all the components, which is accomplished not through the interpretation of the modal dispersion curves but by adopting the FVS (*Full Velocity Spectrum* - Dal Moro, 2014) approach, which does not require the interpretation of the velocity spectra in terms of modal dispersion curves. Furthermore, in addition to the velocity spectra, the HS method also considers the information regarding the ratio between the amplitude spectra of the radial and vertical components (RVSR) and the actual particle motion (RPM frequency curve) (Dal Moro, 2017).

The single-offset active data recorded at the SED site were recorded according to the acquisition parameters reported in Tab. 1 (the HVSR was computed by considering a passive dataset - record time: 2 h; sampling frequency: 200 Hz).

The site is dominated by mudstones and fine-grained sandstones typical of the Swiss foreland basin (see also Dal Moro *et al.*, 2015).

The results of the accomplished joint inversion are summarized in Figs. 2 and 3 (the minimum-distance model represents the model having the minimum geometrical distance from the utopia point - for details see Dal Moro, 2014, 2017).

In spite of the very limited equipment (a single 3C geophone) and consequent limited field effort, the shear-wave velocity (V_S) profile obtained by following the described procedure is in good agreement with the results obtained through the analysis of classical multi-component and multi-offset data and with the available borehole data (Vertical Seismic Profiling - VSP) (see Dal Moro *et al.*, 2015).

Tab. 1 - Acquisition parameters of the active 3C dataset (see Fig. 1).

Recording time	2 s (then reduced to 0.75 s)
sampling frequency	1000 Hz (1 ms)
offset	70 m
stack	5
source	8 kg sledgehammer

Some general conclusions can be drawn:

- a joint inversion is necessarily a sort of compromise between the misfit values of all the considered objective functions and, as a consequence, it is not possible to obtain a perfect match for each single considered object (see also Dal Moro and Puzzilli, 2017);
- the active data recorded by a single 3C geophone can be used for determining up to five objects to exploit for a very-well constrained joint inversion procedure: the group-velocity spectra of the Z, R and T components, the RVSR and the RPM frequency curve;
- the 3C geophone used to record the active data, can also be used to record the passive data useful to compute the HVSR which can be added to the joint inversion, thus further constraining the inversion procedure and increasing the investigated depth otherwise limited to about two thirds or half of the offset adopted for the active acquisition;
- compared to the RVSR, the RPM frequency curve appears less sensitive to subtle stratigraphic details but more robust (less sensitive to data pre-processing);

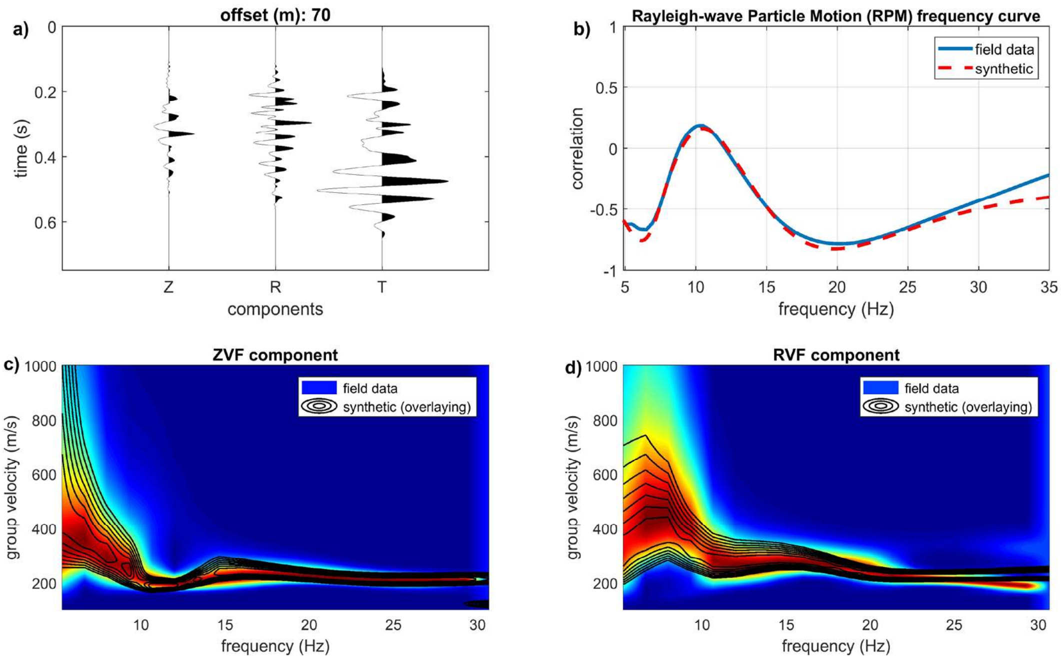

Fig. 2 - Joint inversion of the six considered objects (see also Fig. 3): a) field seismic traces (Z, R and T components); b) field and synthetic RPM frequency curves (Rayleigh waves appear strongly prograde along the entire considered frequency range); c) group-velocity spectra of the ZVF component (background colours represent the field data while the overlying black contour lines the synthetic spectrum of the minimum-distance model reported in Fig. 3d); d) field and synthetic group-velocity spectra of the RVF component.

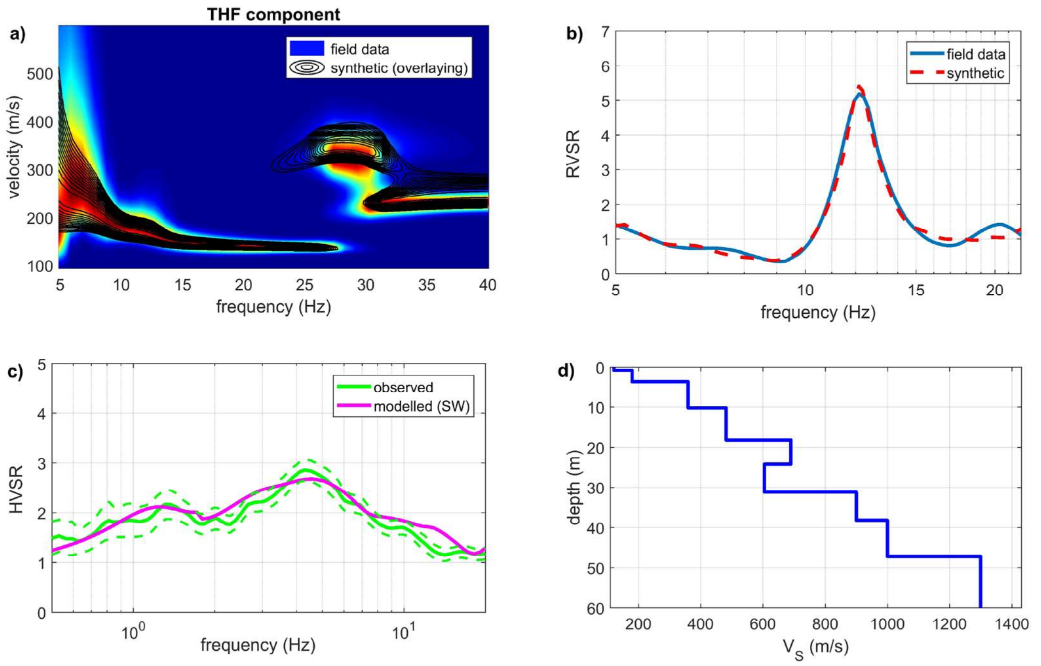

Fig. 3 - Joint inversion of the six considered objects (see also Fig. 2): a) group-velocity spectra of Love waves (THF component); b) field and synthetic RVSR curves; c) field and synthetic HVSRs; d) retrieved VS profile (minimum-distance model).

- in spite of the common belief that Rayleigh waves propagate primarily according to a retrograde motion, prograde motion occurs very frequently and even for very simple subsurface models (such as the one verified in the present case study), away from the classical conditions often invoked to explain it (abrupt V_S changes and high Poisson ratios - Tanimoto and Rivera, 2005; Malischewsky *et al.*, 2008).

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FRACTURED ROCK MASS RESPONSE TO INDUCED VIBRATIONS: PRELIMINARY RESULTS FROM TWO TEST SITES

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Introduction. Rockslides and rockfalls represent one of the most hazardous natural events because of the short time available for taking actions in case of exposed infrastructures due to their rapid evolution as well as their hardly detectable precursors. A recent approach devoted to risk prevention consists in performing ambient vibration studies on potentially unstable fractured rock masses, in order to capture permanent changes in their vibrational response that can be related to a microcracking process or to a variation in the pre-existing fracture net (Got *et al.*, 2010; Levy *et al.*, 2010; Bottelin *et al.*, 2013). As some rock masses are subjected to the action of external vibrations, for instance those located in proximity of railway lines and highways, their behaviour can change through time also because of anthropic reasons beyond the natural ones linked to variations of environmental parameters.