Toward Reliable Characterization of Sites With Pronounced Topography and Related Effects on Ground Motion

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SUMMARY:
Here we present first results of a joint effort undertaken in ongoing European project NERA -JRA1, which aims at establishing scientifically solid and practically acceptable propositions to incorporate surface topography effects in seismic hazard estimates. We assembled a dataset of both ambient vibration and earthquake recordings acquired at 40 European sites with pronounced topography. It comprises a wide variety of sites including populated hills and even extreme cases of unstable rock slopes in Alpine regions. Results of the polarisation analysis for the two sites presented here show the peculiarity of the topographic site effects.

Keywords: Topographic site effects, Data mining, Site characterization

1. INTRODUCTION

The effects of surface topography geometry on seismic ground motion have been recognized for a long time, and have been the topic of many instrumental and numerical investigations over the last four decades. However, their complexity, combined with the limitations of both geophysical investigation techniques and numerical simulation, made it impossible till now to include such effects in earthquake hazard assessment and risk mitigation policies. In a number of cases, observed amplification cannot be explained only by the geometry of the topography, and is probably tightly linked also with local sub-surface structure (e.g., Spudich et al., 1996; Assimaki et al., 2005; Glinsky and Betrand, 2011). Moreover, topographic site effects are also usually linked to co-seismic landslides, which contribute significantly to earthquake damage. However, in case of unstable slopes, purely geometrical effects are almost negligible compared to the combined effect of the topography and subsurface structure (Moore et al., 2011).
Here we present first results of a joint effort undertaken in ongoing European project NERA -JRA1, which aims at establishing scientifically solid and practically acceptable propositions to incorporate surface topography effects in seismic hazard assasment. The key is a reasonable characterization of the both topographic site structures and observed effects on ground motion. Concerning the ground motion analysis, a number of studies found the topographic site effects to be directional (e.g., Bonamassa and Vidale 1991; Spudich et al. 1996; Del Gaudio and Wasowski, 2007; Burjanek et al. 2010; Pischiutta et al., 2010 and 2011; Panzera et al., 2011, Burjanek et al., 2012). Thus we propose the polarization analysis of particle motion as an additional element of the ground motion characterization. We assembled a dataset of both ambient vibration and earthquake recordings

acquired at 40 European sites with pronounced topography. It comprises a wide variety of sites including populated hills and even extreme cases of unstable rock slopes in Alpine regions. This dataset allows a systematic study with common processing tools, providing homogeneous results. The presumed ground motion attributes are sets of azimuthally dependent resonant frequencies, amplifications factors (e.g. with respect to widely used ground motion prediction equations), and near-surface attenuation (e.g. represented by kappa). Concerning structural description of the selected 40 sites, digital elevation models will be analyzed, together with available velocity profiles. A special attention will be paid to reasonable characterization of near-surface rock fracturing and weathering, which generate amplification at presumable rock sites. A systematic comparison of the proposed ground motion and structural attributes should allow the rational classification of the topographic sites, which would further improve the general quantification of the related site effects (e.g. through the numerical simulations). In this paper we present just preliminary results, illustrating mainly the motivation for the study.

2. AVAILABLE DATA

A number of instrumented sites suitable for studying potential topographic effects were identified in Italy, Switzerland, Greece, and France (Fig 2.1). The available data are listed in Tab. 2.1. The sites are located either close to the top of hills and ridges or just in the middle of the slope. Both earthquake (weak motion) and ambient vibrations recordings were collected. The backbone of the dataset consists of the Italian and Swiss permanent seismic stations. Ground motion prediction equations will serve as a reference ground motion for these sites. Most of the Swiss permanent stations have a detailed site characterization including mean velocity profiles down to 30 m, and mean amplification functions relative to the Swiss reference profile (Fäh et al., 2009; Poggi et al., 2011). The rest of the locations are specific experiments related to the local site effects, thus a more detailed geophysical information is available for these sites. Nevertheless, these sites represent mostly extreme cases of the topography-related site effects (e.g., unstable rockslopes in Switzerland).

Table 2.1

	Permanent/Semi-permanent stations				Noise survey	
Site name	Ambient Vibration	Earthquake recordings	Number of stations	Reference station	Arrays	Single station
Italian BB stations	YES	YES	21	GMPE	NO	NO
Swiss BB stations	YES	YES	11	GMPE	2	NO
Aegion	NO	YES	1	YES	1	7
Grevena	YES	YES	1	YES	NO	NO
Narni Hill	YES	YES	10	YES	NO	YES
Nocera Umbra	NO	YES	6	YES	NO	YES
Castelvecchio Subequo	YES	YES	3	YES	NO	YES
Obervaz	YES	YES	1	NO	1	NO
Graechen	YES	YES	3	YES	3	30
Randa	YES	YES	1	YES	3	NO
Walkerschmatt	NO	NO	0	NO	3	NO
Rognes	YES	YES	9	YES	1	YES
Nice	YES	YES	5	YES	NO	YES

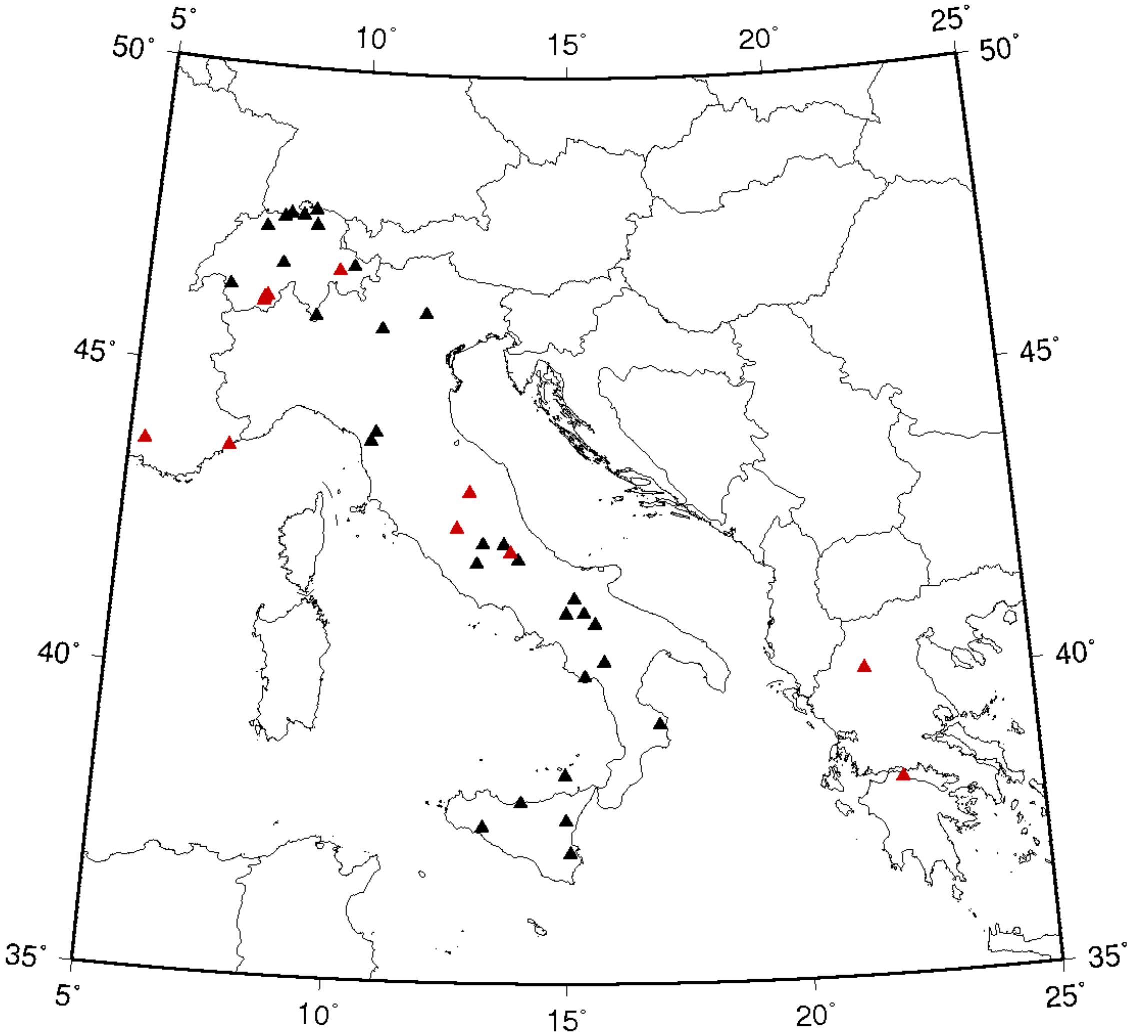

Figure 2.1: Overview of the sites included in the dataset (black: permanent broad-band instruments; red: additional sites with observed topographic site effects).

3. METHODS

Several methods exist for the analysis of the directional site effects. Spudich et al. (1996) introduced directional site-to-reference spectral ratios (SRSR) for the estimation of the relative amplification depending on both frequency and azimuth. This method has been widely applied (e.g., Pischiutta et al., 2010; Massa et al., 2010), however, it requires a reference station, which is not always available. Therefore, a directional non-reference H/V spectral ratio (HVSR) has been also applied (Del Gaudio and Wasowski, 2007). Whereas HVSR has been commonly applied on both earthquake and noise recordings, SRSR has been primarily used with earthquake recordings. Nevertheless, SRSR can be applied also on noise recordings, if it is assured, that the noise generating sources (for frequencies of interest) are far from the site (Roten et al., 2006; Burjanek et al., 2012). In this work, we have focused on the non-reference methods, as the reference is not available for most of the sites.

Recently, Burjanek et al. (2010) introduced time-frequency polarization analysis (TFPA), which is based on the combination of complex polarization analysis (Vidale, 1986) and the continuous wavelet transform (CWT). It can be viewed as a generalization of the directional HVSR method. Three polarization parameters are retrieved: 1) azimuth of the major axis, or strike, measured in degrees from North; 2) tilt of the major axis, or dip, measured in degrees downward from the horizontal; and 3) ellipticity, defined as the ratio between the length of the semi-minor and semi-major axes. All three polarization parameters vary with both time and frequency. Usually, we assume that observed ambient vibrations are quasi-stationary (i.e. noise properties do not change systematically on the time scale of

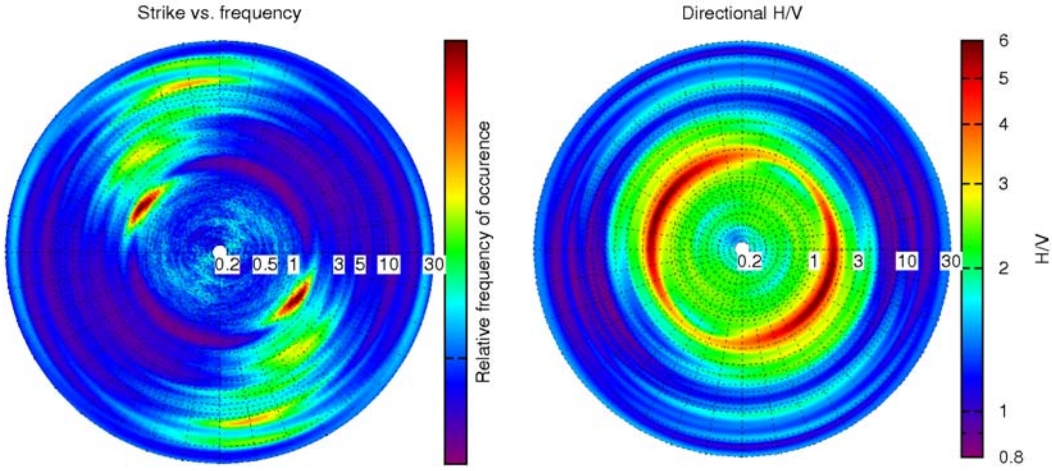

Figure 3.1: Comparison of two processing methods of single station three-component ambient vibration measurements. The relative occurrence of strike (azimuth) of ambient vibrations obtained with time-frequency polarization analysis is presented at left. The directional dependent H/V ratio is presented on right. Frequency changes along the radius from 0.2 to 30 Hz as indicated.

the experiment – a few hours), and analyze the relative occurrence of polarization parameters. In particular, histograms of polarization parameters are constructed over time for each frequency. Polar plots are then adopted for the presentation of final results, which illustrate combined angular and frequency dependence. As the directional HVSR can be used to estimate just the polarization azimuth (orientation in horizontal plane), TFPA method provides also information on the inclination of the particle motion (dip). Moreover, the use of CWT maintains optimum time-frequency resolution, which can be smoothly regulated by an adjustment of the mother wavelet. An example of the direct comparison of the directional HVSR and relative occurrence of azimuth (strike) obtained with TFPA for a common recording of ambient vibrations is presented in Fig. 3.1. TFPA clearly outperforms directional H/V providing better directional resolution.

4. PRELIMINARY RESULTS

Here we present a result of the polarization analysis using TFPA for two stations of the Swiss network. These two stations were selected as they represent two end cases (strong directional site effect vs. no directional site effect).

At first we present results for the station FLACH, which is located in the middle of the slope (Fig 4.1a). The site is instrumented with three component velocity sensor with an Eigen-period of 5 sec. Two hours of ambient vibration recording were processed. The results of TFPA are presented in Fig. 4.1. Note the drop of the ellipticity at the frequency of 4 Hz (particle motion is almost linear for most of the time). Moreover, strike (azimuth) concentrates around 95° for the same frequency (4 Hz). The observed direction (95°) is transversal to the topography elongation. An analysis of 9 earthquake recordings was also performed. Results are presented in Fig. 4.2. Generally, similar pattern is observed as for the ambient vibrations, just the minimum of the ellipticity is shifted to 5 Hz. Nevertheless, this might be related to the relatively low number of available earthquake recordings. To conclude, site FLACH presents a typical example of the directional site effect.

At second, we present results for the station BALST, which is located just on the cliff (Fig. 4.3a), where a strong topographic site effect is expected. The site is instrumented with three component velocity sensor with an Eigen-period of 120 sec. Two hours of ambient vibration recording were processed. The results of TFPA are presented in Fig. 4.3. No specific polarization pattern is observed, apart from high-frequency disturbance, which is probably related to a local human activity. An analysis of 17 earthquake recordings was also performed. Results are presented in Fig. 4.4. Similarly to ambient noise recordings, no specific polarization pattern is observed. Concluding, site BALST does not present any strong directional site effect.

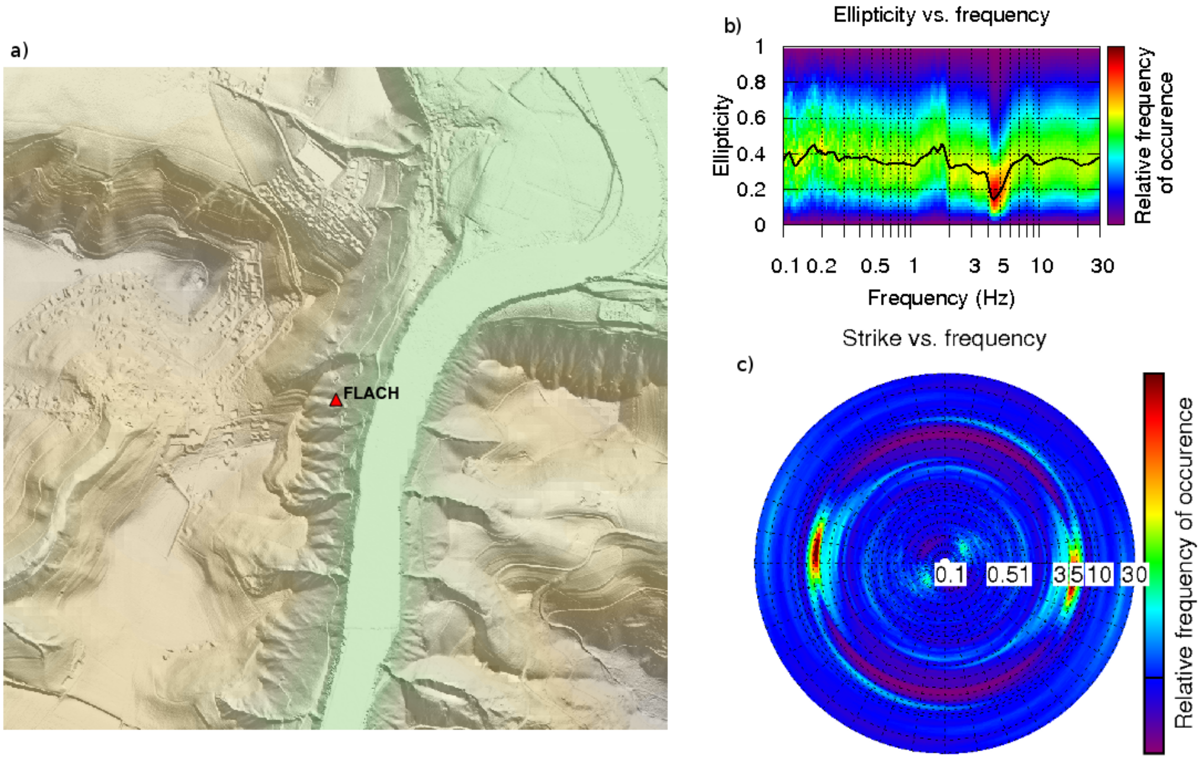

Figure 4.1: a) Site FLACH (+ surrounding area of 2 km x 2 km), the height of the ridge is approximately 150 m. b) Relative frequency of occurrence of ellipticity in ambient vibrations retrieved by TFPA. The mode of the ellipticity distribution is interconnected with the black line; c) Relative frequency of occurrence of strike in ambient vibrations retrieved by TFPA.

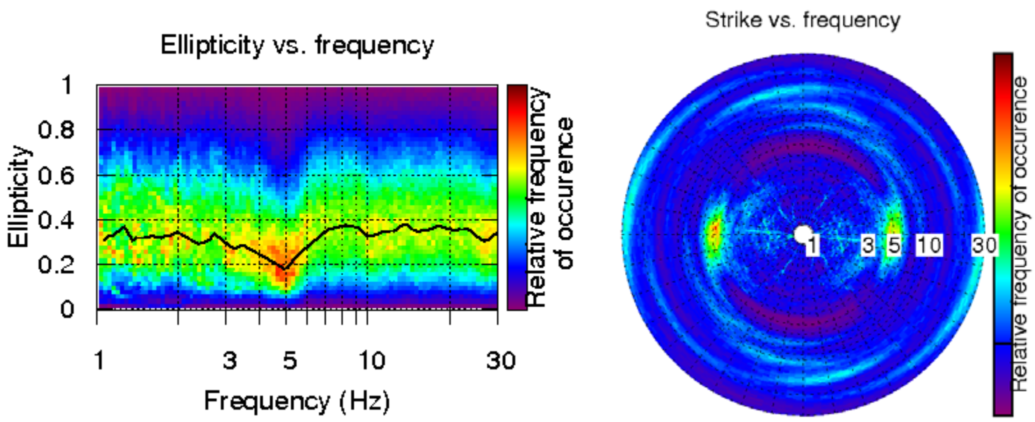

Figure 4.2: TFPA analysis of earthquake recordings at station FLACH: ellipticity distribution (on left) and strike distribution (on right).

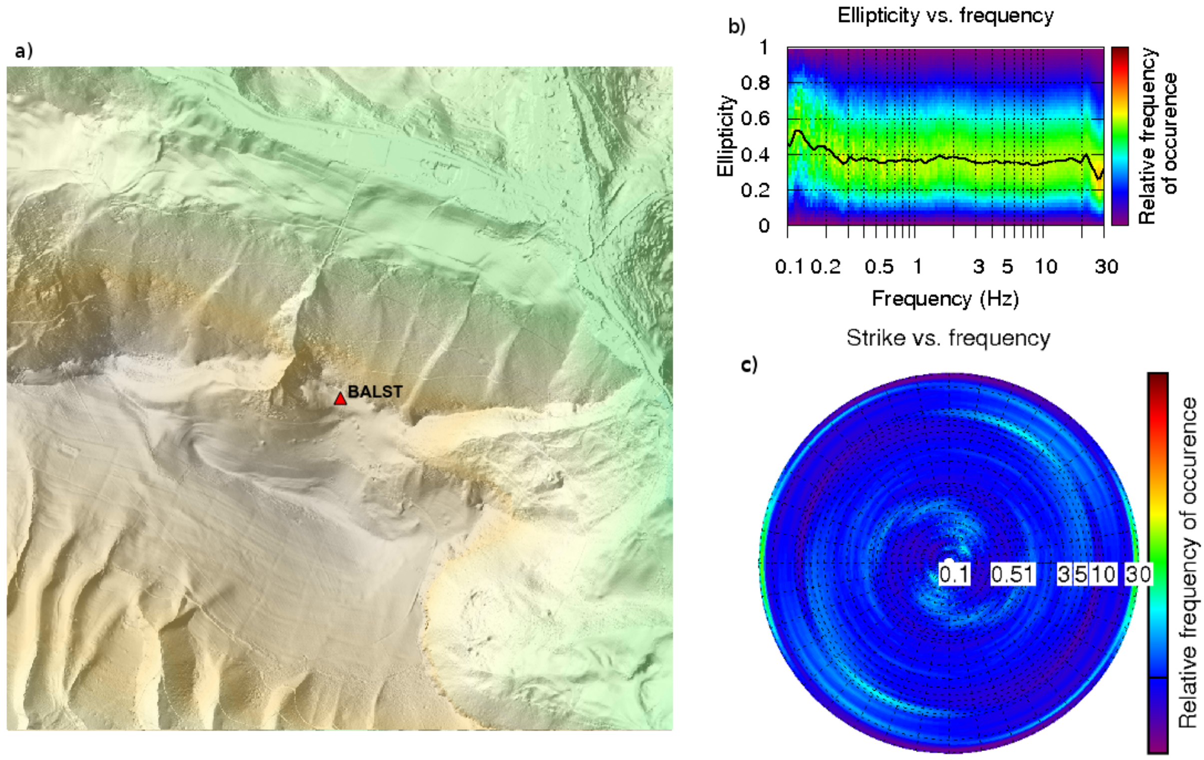

Figure 4.3: a) Site BALST (+ surrounding area of 2 km x 2 km), the height of the ridge is approximately 300 m. b) Relative frequency of occurrence of ellipticity in ambient vibrations retrieved by TFPA. The mode of the ellipticity distribution is interconnected with the black line; c) Relative frequency of occurrence of strike in ambient vibrations retrieved by TFPA.

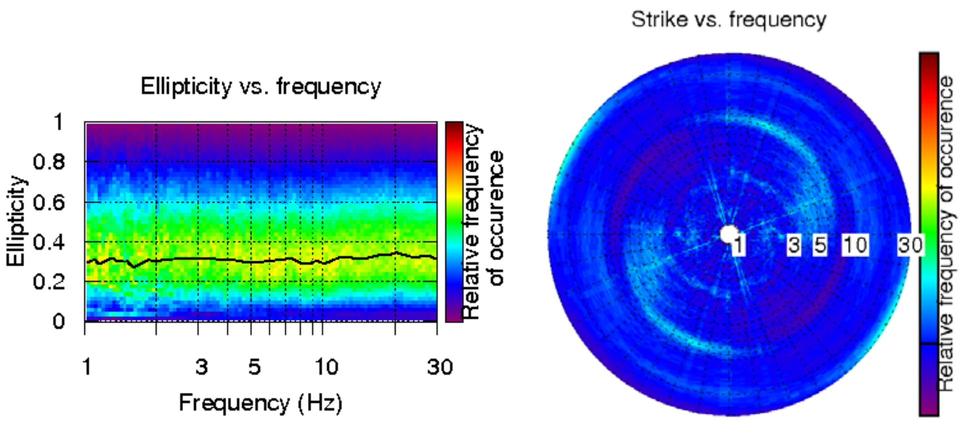

Figure 4.4: TFPA analysis of earthquake recordings at station BALST: ellipticity distribution (on left) and strike distribution (on right).

5. CONCLUSIONS AND OUTLOOK

The two sites presented here, show the peculiarity of the topographic site effects. Average residuals with respect to Swiss ground motion prediction model (GMPE) were also calculated for the two stations (Edwards, personal communication), and confirm the results presented here – station FLACH shows a mean amplification of 5 at 5 Hz with respect to the Swiss reference profile (Poggi et al., 2011), whereas station BALST does not show any amplification at specific frequency based on the data used herein.

The project NERA is now in its second year. The work on topographic site effects has started in summer 2011, and conclusive results are expected after processing of the complete dataset. Moreover, set of new geophysical experiments is planned at selected sites in the framework of the project, and will help with the interpretation of the available station recordings.

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