

COMBINING PASSIVE-GEOPHYSICAL AND STRATIGRAPHIC DATA FOR A PRELIMINARY MAPPING OF THE PO PLAIN SEISMIC BEDROCK (NORTHERN ITALY)

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According to the actual Italian and European seismic codes (NTC, 2008; CEN, 2003), the transition between soft and hard soil is ascribable where the shear-wave velocity exceeds 800 m/s. This interface represents the *seismic bedrock* and it is of relevant importance for the seismic site effects evaluation. This issue is particularly significant in the Po alluvial basin, which is the deepest and most extended sedimentary basins in Italy. The recent case of the 2012, M_w 6.1, Emilia (Northern Italy) seismic sequence highlighted the importance of the site effects estimation in the Po Plain, where despite the low-to-moderate seismic hazard, the high density of both population and infrastructure makes this area a high seismic-risk zone.

The aim of this work is to preliminary map the Po Plain *seismic bedrock* through the association of the available passive geophysical analysis and the known regional stratigraphic discontinuities.

This study is based on an extensive collection of geophysical and geological data in the entire area. In particular:

- all permanent and temporary (i.e. seismic emergency or project) seismic stations installed in the area in the previous years and now available, for a total of 73 measure points;
- 56 new single station measures of ambient noise have been performed throughout the basin in order to obtain a regular grid of equidistant measures;
- 8 microtremor array measurements recently executed in the framework of several projects;
- borehole data if available, in particular the cross-hole tests in Medolla, Mirandola (Paolucci *et al.*, 2015; Laurenzano *et al.*, 2017) and Casaglia (Laurenzano *et al.*, 2013), besides the down-hole test in Mirabello (Minarelli *et al.*, 2016);
- a huge dataset collected by Regione Emilia-Romagna, with 60 shear-wave velocity profiles and 2000 H/V executed in the Po Plain area, has been reviewed and selected obtaining a representative subdataset composed of 47 single station measure and 15 microtremor array measurements;
- regarding the stratigraphic data, different regional unconformities corresponding to different aquifers limits have been extensively mapped throughout the basin in two subsequent publications (i.e. Regione Emilia-Romagna, ENI – AGIP, 1998; Regione Lombardia, Eni Divisione Agip, 2002). These works have been the primary source of geological and stratigraphic information. However, other different studies in the Po Plain area have been considered (e.g. Pantaloni 2007; Scardia *et al.*, 2012; Fantoni and Franciosi 2010; Fontana *et al.*, 2014; GeoMol Team 2015; Martelli *et al.*, 2017).

All available data of ambient noise (Fig. 1) were analyzed with the Nakamura technique (Nakamura, 1989) to determine the H/V amplification function and the collected microtremor array measurements were homogeneously reprocessed to obtain the relative shear-wave velocity profile, through a joint inversion of the Rayleigh wave dispersion curve (fundamental mode only) and the ellipticity curve estimated from the H/V results. Moreover, 71 H/V curves were inverted with the Sanchez-Sesma *et al.* (2011) method in order to obtain the correspondent velocity profile for 71 scattered sites in the basin (Fig. 2). Based on these analyses, the H/V peaks corresponding to the seismic bedrock interface have been selected and a frequency-depth

empirical relation has been developed for the study area, allowing preliminary mapping the Po Plain seismic bedrock. The method proposed in Paolucci *et al.* (2015) for estimating depth of the resonant interfaces has also been applied and compared. In this case, the frequency-depth relation has been performed with the Eq. (1) (Ibs Von Seht and Wohleberg, 1999),

$$H \cong \left[\frac{V_0(1-x)}{4f_0} + 1 \right]^{\frac{1}{1-x}} - 1 \tag{1}$$

estimating the necessary coefficients (V_0 and x) from curves of the average V_s values up to any value of the depth h .

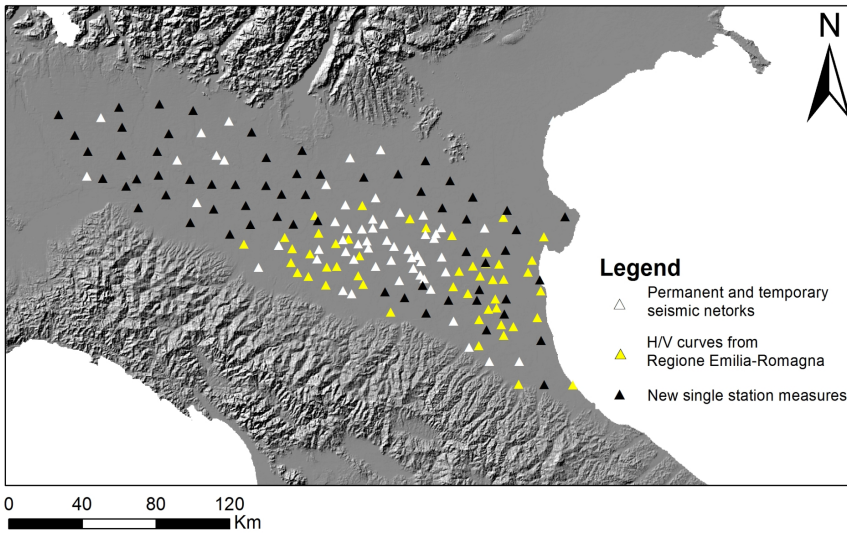


Fig. 1 - Available data of ambient noise, located throughout the basin. White triangles: H/V from permanent and temporary seismic networks; yellow triangles: H/V curves selected from the dataset of Regione Emilia-Romagna; black triangles: H/V from single station measures.

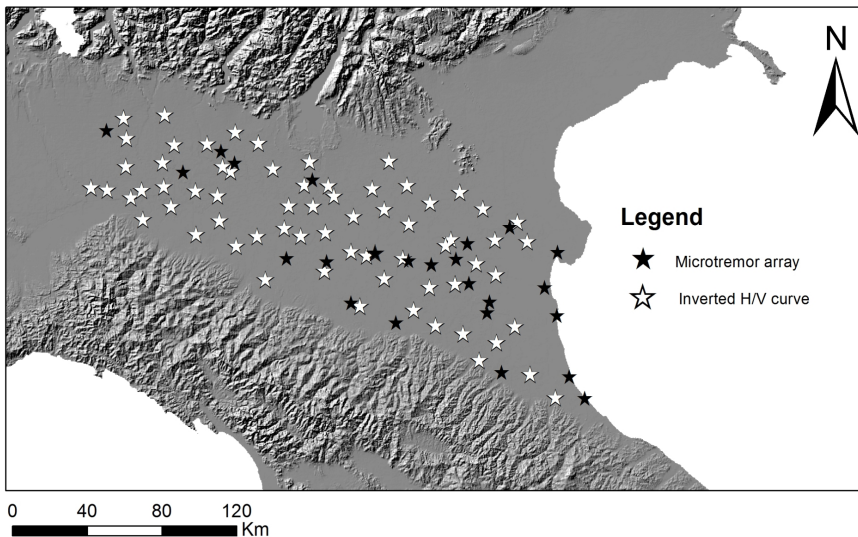


Fig. 2 - Available shear-wave velocity profiles. Black stars: velocity profiles from microtremor array (i.e. data set of Regione Emilia Romagna; DPC-INGV 2014-2015 S2-seismological project; DPC-INGV 2016-2017 agreement, All. B2); white stars: velocity profiles from inverted H/V curves.

Finally the seismic bedrock interface has been mapped throughout the basin, showing values in general ranging between 100 m and 300 m of depth, deepening toward the Adriatic Sea, where the velocity gradients are lower and the H/V peak corresponding to the seismic bedrock interface moves at lower frequencies. The seismic bedrock interface appears related to different stratigraphic discontinuities based on the zone. In particular, in the western part of the plain near Pavia and Milano, it seems corresponding to the base of the 2nd aquifer (Regione Emilia-Romagna, ENI – AGIP, 1998; Regione Lombardia, Eni Divisione Agip, 2002), except for a few stations in the northern sector where it may be related to a deeper surface. In the central and most extended part of the Plain, it could be related to the base of the 1st aquifer (Regione Emilia-Romagna, ENI – AGIP, 1998; Regione Lombardia, Eni Divisione Agip, 2002), but for those sites in the northernmost sector (near the Garda Lake) and for some in the southernmost sector (near the Apennines) it seems still related to the base of the 2nd aquifer. For the stations in correspondence of the top of the buried structural highs of S. Colombano, Mirandola and Casaglia (Pieri and Groppi 1981; Martelli and Romani 2013), the seismic bedrock interface could be related to the base of the Quaternary sediments, in correspondence of the contact with Low-Pliocene or Miocene Marls, raised to shallow depth by buried structural highs. East of Ferrara Arc (Pieri and Groppi 1981), the seismic bedrock interface deepens toward the Adriatic Sea and it could be related to a deeper discontinuity inside the 2nd aquifer.

The preliminary map of the Po Plain *seismic bedrock*, allows for a site effects estimation useful for both scientific and applied purpose. In particular, considering that in the target area the seismic bedrock interface lies well below the depth range (0-30 m) considered in the engineering practice (MASW, refraction, etc.), this study can be a benchmark for local seismic response analyses and new hazard studies at regional scale, when just Near-Surface Geophysics is available.

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