The local seismic response of the Fosso di Vallerano valley (Rome, Italy) based on a high-resolution geological model

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ABSTRACT

The main purpose of this study is the analysis of the local seismic response in the Fosso di Vallerano valley, an alluvial basin located in a recently urbanized area of Rome (Italy). A high-resolution geological model was obtained starting from 250 available borehole log stratigraphies and pressuremeter in-site tests; the model highlighted a complex and heterogeneous setting of both the local substratum and the alluvial fill. The local seismic-stratigraphy was derived based on several noise measurements as well as one cross-hole test. A preliminary validation of the stratigraphic model was performed by modeling the amplification functions (SSR) derived from weak motions recorded on August 2009 through a temporary velocimetric array. The obtained results show that the recent alluvial deposits have one principal mode of vibration at about 0.8 Hz and different secondary vibrational modes due to the characteristic stratigraphic setting of the alluvia. The seismic bedrock can be located within the Paleo Tiber 4 deposits (Santa Cecilia Formation) by assuming a velocity gradient in these deposits (i.e. corresponding to the Vs increment from about 500 m/s up to 1100 m/s).

KEY WORDS: local seismic response, geological model, seismic-stratigraphy, Rome.

INTRODUCTION

The Fosso di Vallerano valley is located in the southern part of Rome (Italy), on the left side of Tiber River and is composed by two minor alluvial valleys isolated by the Castellaccio hill that join (12 m a.s.l.) before the confluence with the Tiber River valley. The site was selected as case study due to its interesting geomorphology and its highly heterogeneous geological setting. Furthermore it is one of the most recently urbanized areas in Rome and hosts in the “Europarco Business Park” the highest buildings (120 m) currently present in the city. This study aims at laying the foundations for future studies focusing on the “Site-City Interaction” (Semblat et al., 2009) to assess the influence of urban agglomerates on the local seismic response. In this perspective, the availability of geophysical data recorded before the strong urban development of the Fosso di Vallerano valley, can provide an important contribution to the evaluation of the progressive influence of buildings on the local seismic response.

GEOLOGICAL SETTING

The geological evolution of the Rome urban area results from the combination of a series of factors. An initial Miocene to Early Pleistocene extensional tectonic phase, which is related to the Apennines back-arc evolution, was responsible for the opening of a series of marine basins. This phase was followed, during Middle-Upper Pleistocene by the continentalization of the area, controlled by a complex interplay of tectonics, fluvial to coastal sedimentation in close connection with sea level oscillations, and the activity of the Volcanic District surrounding the city (Marra & Florindo, 2014). The clayey to sandy deposits of three main sedimentary cycles related to as many marine transgressions represent the geologic bedrock at Rome. More in particular, these deposits are ascribable to the Marne Vaticane Formation (Pliocene- Early Pleistocene, Marra et al., 1995); the Monte Mario Formation and the Monte delle Piche Formation. The progressive depth reduction of the sedimentary basins, testified by the increase in grain size of the deposits, is related to the progressive uplift of the Latium Tyrrenian margin, that led to the complete emersion area during Middle Pleistocene. The deposition of the Monte Cioci/Monte delle Piche Formation and of the following Paleo-Tiber units near the coastal area are in fact strictly connected with the glacial-eustatic sea oscillations (Marra & Florindo, 2014). Through the combined stratigraphic, geochronologic and paleomagnetic study of the sequence deposited by the Paleo-Tiber River (Marra & Florindo, 2014) and its tributaries, it is possible to identify 10 aggradational successions corresponding to as many glacial terminations, encompassing Marine Isotopic Stage (MIS) 22/21 through 2/1.

ENGINEERING-GEOLOGICAL MODEL

In order to obtain an engineering-geological model of the valley, field investigations were integrated with 250 borehole log-stratigraphies, as well as expeditious geomechanical on-site
surveys (Pocket-Penetrometer and Pocket Vane-test) available from technical reports and official achieves (Bozzano et al., 2000; Ventriglia, 2002; Marra F. Database Personale). The here considered boreholes are distributed over an area of about 25 km². Based on the derived log-stratigraphies, 4 main lithostratigraphic groups were distinguished:

- Plio-Pleistocene Marine sediments (PP) (Marne Vaticane, Monte Mario e Monte Ciocci/delle Piche Formations) that represent the geological bedrock of the area;
- Pleistocene alluvial sediments deposited by the Paleo-Tiber 4 River (PT) (Santa Cecilia Formation; 650-600 ky; Marra & Florindo, 2014);
- Volcanic deposits erupted from the Alban Hills and the Monti Sabatini Volcanic District (VC)(561-365 ky);
- Recent alluvial deposits filling the valley incisions since the end of the Würmian regression to the present (AL)(18 ky-Present);

Several geological cross sections were realized by correlating all the available boreholes and were used to reconstruct a 3D geological model of the Fosso di Vallerano area. In this paper only the cross section reported in Figure 1, is taken into account. The main outcome of the 3D reconstruction consists in the evidence of a highly heterogeneous alluvial deposits, characterized by both vertical and lateral contacts among the different lithotechnical units. In particular, the recent alluvia (AL) are characterized: i) in the upper portion, by two lithotechnical units which are present in the entire valley: man-made fill deposits (AL-FL) and sandy-clays deposits with a marked volcanic component (AL-VSC); ii) in the middle portion by clays and silts (AL-CS), that are mainly located in the eastern part of the valley, while peaty clays (AL-PC) and peat (AL-PT) are prevalent in the western zone; iii) in the basal portion by a gravel layer (AL-GR) somewhere characterized by lateral contacts with sandy deposits (AL-SD). Finally, the Pleistocene alluvial sediments ascribable to the Paleo-Tiber 4 River (PT) are composed by a mainly clay and silty layer (PT-CS), which is locally layered by sands (PT-SD) or gravels (PT-GR).

SEISMOMETRICAL DATA

In the period 2009-2014, five ambient noise surveys were carried out in the Fosso di Vallerano valley, using three different triaxial velocimetric stations. The first survey was performed by a 4Hz digital tromometer TROMINO (Micromed) set to a 128 Hz sampling rate, that acquired noise samples 20 minutes long in different hours of the day. Since 2012 four further surveys were realized by a 1.4 Hz SL06 acquisition system (SARA Instruments) set to a 200 Hz sampling frequency and a LENNARTZ LE3D/5s sensor coupled with a Reftek 130 digitizer set to a 250 Hz sampling frequency. Noise records from 45 minutes to 2 hours long were acquired in different hours of the day. The records, sampled with a 40 s moving time window, were de-trended, tapered, converted to the frequency domain and smoothed by a Konno-Ohmachi function (b=40) to get average HVSR (Horizontal to Vertical Spectral Ratio) according to Nakamura (1989). The ambient noise analysis shows a homogeneous response of the valley with a fundamental resonance frequency of 0.8±0.1 Hz, the relived areas, instead, show no significant resonance peaks of the HVSR functions (Fig. 1).

From June to July 2009 a free-field seismometric array, installed by the University of Rome “Sapienza” in co-operation with ENEA, operated in STA/LTA (Short Time Average to Long Time Average) acquisition mode in the Fosso di Vallerano valley. The array was composed of two stations each one instrumented by three single component, 1 Hz velocimeters (SS1 Kinematics) triaxially arranged, connected to a 24bit data logger (K2 Kinematics) and a GPS device for absolute timing. One station (Valle) was located on the alluvial deposits, in the NE sector of the valley. A reference station (sensu Borcherdt, 1994) was placed on the local seismic bedrock, corresponding to the volcanic hills that border the valley, where no evidence of amplification was pointed out by noise records. The seismometric array recorded overall about 30 earthquakes in the magnitude range 2.6-4.6, mainly from Central Alpenines seismic sources.

The recorded earthquakes were processed in the frequency domain to achieve both the average receiver functions (RF) (Lermo et al., 1993) and the average standard spectral ratio
The amplification effect was ing the experimental data and the model outputs. The obtained results confirmed the high quality of the reference station, since no significant amplification effect was pointed out; on the contrary, both the RF and the SSR functions derived for Valle station showed a well defined peak at 0.8 Hz, in agreement with the results of ambient noise measurements.

LOCAL SEISMIC RESPONSE

CALIBRATION OF THE SEISMO-STRATIGRAPHIC MODEL

Based on the available high-resolution geological reconstruction, a 1D numerical modeling through EERA code (Bardet et al., 2000) was performed with the aim of deriving the local seismo-stratigraphy. The analysis focused on the soil column obtained in correspondence to the velocimetric station Valle. The weak motion records were used to calibrate the model and to evaluate the role of each seismo-layer on the local seismic response of the site.

The calibration was carried out by direct comparison between the results obtained from the recorded data (SSR) and the outputs from the numerical modeling, i.e. the amplification functions A(f). In particular, the stratigraphy derived from the high resolution geological reconstruction was fixed, while different wave S velocity (Vs) values were assumed within the soil column until the best fit with the measured data was obtained. The starting Vs distribution was derived from the only cross-hole survey available in the study area.

The Vs profile shown in Figure 2a corresponds to the best fit between the experimental data and the model outputs. The resulting differences between the modeled and the recorded A(f) functions can be attributed to 2D effects due to both the valley shape and the heterogeneous soil filling that cannot be modeled by the 1D EERA code.

The here obtained Vs profile (Fig. 2a) is largely in agreement with other literature data (Bozzano et al., 2008; Caserta et al., 2012) but points out a different value for the AL-VSC deposits (i.e. Vs value according to literature is 180 m/s, instead the value deduced from our analysis is 350 m/s) and a velocity gradient in the clay and silt deposits of the Santa Cecilia Formation (PT-CS), i.e. corresponding to a Vs linear increment, according to Bozzano et al. (2008) and Caserta et al (2012), from about 500 m/s up to 1100 m/s.

The calibration process allowed to evaluate the role of each seismo-layer on the seismic response of the soil column. In particular all the deposits sited on the seismic bedrock, i.e. recent alluvial body (AL) and the clay and silt deposits of the Santa Cecilia Formation (PT-CS) influence the first resonance mode (1 Hz). The characteristic “trough shape” of the function (2-6 HZ) is due to the Vs inversion between the sandy-clays characterized by a marked volcanic component (AL-VSC) and the peaty clays (AL-PC). The peaks between 7 -10 Hz are instead controlled by the Vs contrast between human filling deposits (AL-FL) and sandy-clays deposits with a marked volcanic component (AL-VSC).

LOCAL SEISMIC RESPONSE ALONG THE CROSS SECTION

The obtained seismo-stratigraphic model of the subsoil was extrapolated to be applied to the geological cross section in Figure 1; it was discretized by 56 soil columns each one having a lateral representativeness of about 10 m, in order to obtain the spatial distribution of the A(f) under free field conditions, assuming a 1D elastic model. The contour map of the obtained A(f) (Fig. 3a) points out the stratigraphic effect only, i.e. it is influenced by the thickness of the alluvial deposits (including
recent alluvia and part the Paleo-Tiber 4 deposits) as well as by the seismic bedrock depth. In particular, it is worth noticing that where the thickness of the resonant deposits is about 60-65 m, the range of the first resonance mode is very narrow (0.8-1.0 Hz). On the contrary, in the portion of the valley where the thickness of the resonant deposits significantly decreases (15-20 m) due to the local structural setting, the first resonance mode corresponds to higher values (2.0-4.5 Hz); moreover, in this portion it is possible noticing that the absence of the clay and silt deposits of the Paleo-Tiber 4 (PT-CS) induces a stronger impedance contrast between the resonant deposits and the seismic bedrock, leading to higher amplification levels. The secondary resonance modes, in terms of both frequency value and amplification level, are related to the different seismo-stratigraphic conditions of each soil column.

It is worth noticing that in Fosso di Vallerano valley the seismic bedrock is located at the top of the Paleo-Tiber 4 gravel (Pleistocene) and it does not correspond to the geological bedrock (i.e., the Holocene/Pleistocene discontinuity contact); this is a relevant difference respect to the main Tiber River valley where the seismic bedrock, according to Bozzano et al. (2008) is coincident with the Holocene gravel of the G level. The obtained A(f) distribution is determined by 1D stratigraphic layering only and can take into account nor the lateral heterogeneity of the alluvial filling neither the shape of the valley (2D effects). However it is reasonable to think that the local seismic response and the seismically-induced effects in heterogeneous geological settings are significantly conditioned by 2D effects, in terms of both amplification and shear strain distribution, as demonstrated by Giacomini, 2013 for the Tiber River valley in the historical centre of Rome.

Given these observations, the here obtained results can be considered as a starting point for quantifying properly 2D seismic effects along the analyzed section.

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