

Analysis of Site-City Interaction in Rome Due to Recent Urbanization: Geological Modeling and Preliminary Numerical Results

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ABSTRACT

This paper shows the results of a study focusing on the local seismic response of the Fosso di Vallerano valley (Rome, Italy). These results represent the starting point for future evaluations of the changes expected for the same local seismic response in the case of the presence of buildings (i.e. Site-City Interaction). This test site was selected for the following reasons: i) it is characterized by a complex geological setting; ii) it represents a very recent urban area. A detailed structural and stratigraphic setting of the valley was obtained by field investigations and by correlating several tens of borehole log-stratigraphies. All these parameters have been considered in a 1D numerical modeling performed to estimate the resonant frequencies and the related amplification values for the site under free field conditions. This analysis pointed out the relevant role of the layering of the subsoil deposits on the local seismic response.

Introduction

The Fosso di Vallerano valley (Rome, Italy) was selected as case study to evaluate the Site-City Interaction (SCI - Kham et al. 2006; Semblat et al. 2008), i.e. the influence of buildings on the local seismic response and on the seismically-induced effects of alluvial fills. The valley was chosen as it is characterized by a highly heterogeneous geological setting and it is one of the most recent urbanized areas in Rome. More in particular, Fosso di Vallerano valley hosts the “Europarco Business Park” i.e. the highest buildings (120 m) in Rome. A first phase of the study was focused on the reconstruction of the engineering-geological model of the valley through geological maps and cross-sections and a second phase is consisting in 1D numerical modeling propaedeutic to 2D numerical modeling of the seismic response in free field conditions as well as by considering the system city agglomerate, according to a SCI approach. Some preliminary results of this study are here presented.

Engineering-geological model

The Rome urban area is located in a peculiar geodynamic context on the Tyrrhenian Sea Margin, at the transition between northern and central Apennines, which results from combined glacio-eustatic, sedimentary, tectonic and volcanic processes from the Pliocene to present (Milli et al. 2008; Karner & Marra 1998; Marra et al. 2008; Sottili et al. 2010). To reconstruct the complex geological setting of the valley, 250 log stratigraphies from boreholes were considered as well as in-site geomechanical investigations, available from technical reports and official documents

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(Bozzano et al. 2000; Ventriglia 2002; Marra F. Personal database). Based on such data four main lithotechnical units were distinguished in the Fosso di Vallerano valley: i) Plio-Pleistocene Marine deposits (Marne Vaticane Formation) composed by high consistency clays with silty-sandy levels; ii) Pleistocene alluvial deposits of the Paleo Tiber 4 River (650-600 ky) composed by soils including graves, sands and clays; iii) Volcanic deposits of the Alban Hills and of the Monti Sabatini Volcanic Districts (561-360 ky) consisting of highly heterogeneous tuffs; iv) Recent alluvial deposits that filled the valley incisions since the end of the Würmian regression (18 ky-Present), characterized by a basal gravel level and including by different soft soils from sands to inorganic or peaty clays.

In particular, the Plio-Pleistocene Marine deposits represent the local geological bedrock. Mechanical and dynamic properties were attributed to each lithotechnical unit according to literature data (Bozzano et al. 2008; Caserta et al. 2012).

The geological model was integrated by a geophysical dataset available from field surveys in order to provide an high-resolution engineering-geological model of the valley. In the June-October 2009, 3 ambient noise surveys were carried out in the Fosso di Vallerano Valley, using a 4Hz digital data-logger TROMINO (Micromed) set to a 128 Hz sampling rate; in the June – October 2014 additional campaigns of ambient noise records were carried out in the valley, using a Lennartz seismometer LE-3D/5s set to a 250 Hz sampling rate. The ambient noise analysis, performed according to the HVSR (H/V spectral ratio) Nakamura technique (Nakamura 1989) pointed out a stratigraphic seismic response of the valley with a fundamental resonance frequency of about 0.8 Hz. On the other hand, no amplification resulted in the surrounding hills where volcanic deposits widely outcrop. From June to July 2009 a free-field velocimetric array operated in STA/LTA (Short Time Average to Long Time Average) acquisition mode in the Fosso di Vallerano valley, in order to record low-middle magnitude earthquakes during the tail of the L'Aquila seismic sequence. This array was composed of two stations only corresponding to a reference site on stiff bedrock and to a soft-soil site in the Fosso di Vallerano valley. The computed receiver functions (Lermo et al.1993) of the recorded events confirm the results obtained from the HVSR derived by the noise measurements.

Structural and dynamic characterization of the buildings

The Fosso di Vallerano valley is a portion of Rome characterized in the last decades by a strong urbanization. The urban agglomerate is mainly composed by residential buildings, characterized by rectangular or square geometry and height varying from 6 m up to 25 m; under the structural point of view, these edifices consist of concrete reinforcing structures. The valley also hosts particular kinds of buildings that are part of the “Europarco Business Park” and include the two skyscrapers (named “Europarco Tower” and “EuroSky Tower”) that are 120 m and 155 m high, respectively. These towers are characterized by a rectangular plan geometry and they are constituted by a steel structure.

To evaluate the characteristic oscillation period of each building, the relationship (Equation 1) provided by the Italian technical standards (NTC08) was applied:

$$\{C\} + \{H\}^{3/4} = \{T\} \quad (1)$$

In which $\{T\}$ is the characteristic oscillation period, $\{H\}$ is the height of the building and $\{C\}$ is a Constant value (0.075 for concrete reinforcing structures and 0.085 for steel structures).

The here calculated characteristic oscillation periods for the skyscrapers is 3s and for the civil buildings varies in the range 0.3-1.0s.

Numerical modeling

In the last decades great efforts were aimed at seismic response numerical modeling since it represents a powerful tool for validation and prediction of physical phenomena related to the seismic wave propagation in problems of civil engineering and earthquake geotechnical engineering. The numerical modeling actually represents the main tool to estimate local seismic response and seismically-induced effects, particularly in the urban area (Rovelli et al. 1994; 1995; Bonilla et al. 2010; Semblat and Pecker 2009) where the geophysical measurements are often not suitable for highlighting the local seismic response.

Calibration of the seismo-stratigraphic subsoil model

A calibration process was performed by using the seismometric records collected in the Fosso di Valerano study area and the outputs from a 1D numerical modeling performed by EERA code (Equivalent – linear Earthquake Response Analysis, Bardet et al. 2000) to refine the seismo-stratigraphy of the Fosso di Vallerano valley as well as to highlight the role of the lithotechnical unit layering on the amplification function ($A(f)$). Based on the available high-resolution geological model, the calibration process was performed by only varying the shear wave velocity (V_s) of each lithotechnical units. To best fit the numerical model the $A(f)$ derived from the recorded weak motions were de-convoluted to the local seismic bedrock corresponding to the reference site. At this aim, the soil column corresponding to the soft-soil site of the velocimetric array was selected (Fig. 1a).

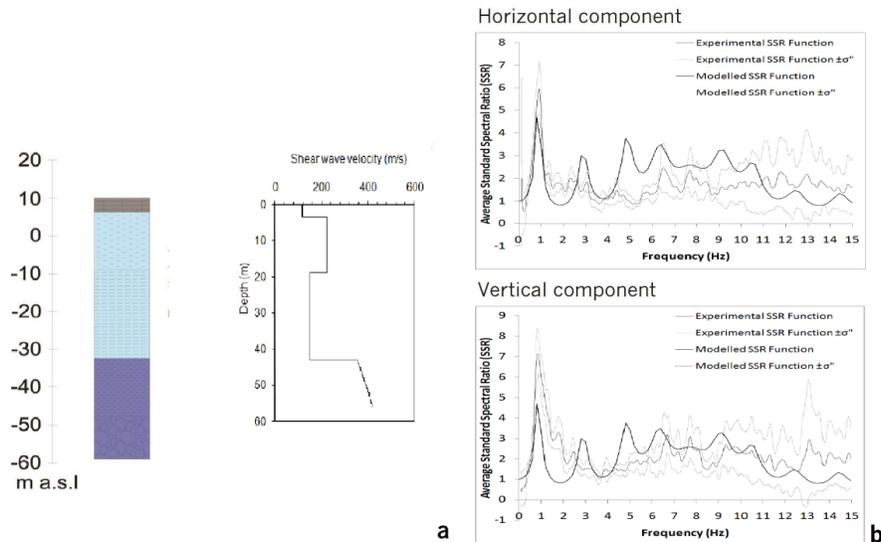


Fig 1: Results of the calibration process: a) V_s profile corresponding to the best fit. b) Comparison between numerical and experimental $A(f)$.

The average Site-to-reference Spectral Ratios (SSR) obtained from the recorded weak motions (Borcherdt 1994) were compared with the $A(f)$ obtained from the 1D numerical modelling performed by assuming different V_s values for the log-stratigraphy of the considered soil column. The V_s profile shown in Figure 1a corresponds to the best fit between the records and the model outputs (Fig. 1b). The remnant differences between the modeled $A(f)$ and the recorded SSR can be attributed to 2D effects due to both the valley shape and the heterogeneous soil fill that cannot be modeled under 1D assumptions.

Results of the 1D numerical modeling

The seismo-stratigraphic model of the subsoil was extrapolated to carry on a 1D modelling along the geological cross-section through the “Europarco Business Park”, performed by discretizing it in 56 soil columns, whose lateral representativeness is of about 10 m. Also this modelling was performed by the EERA code by assuming a visco-elastic rheological behavior.

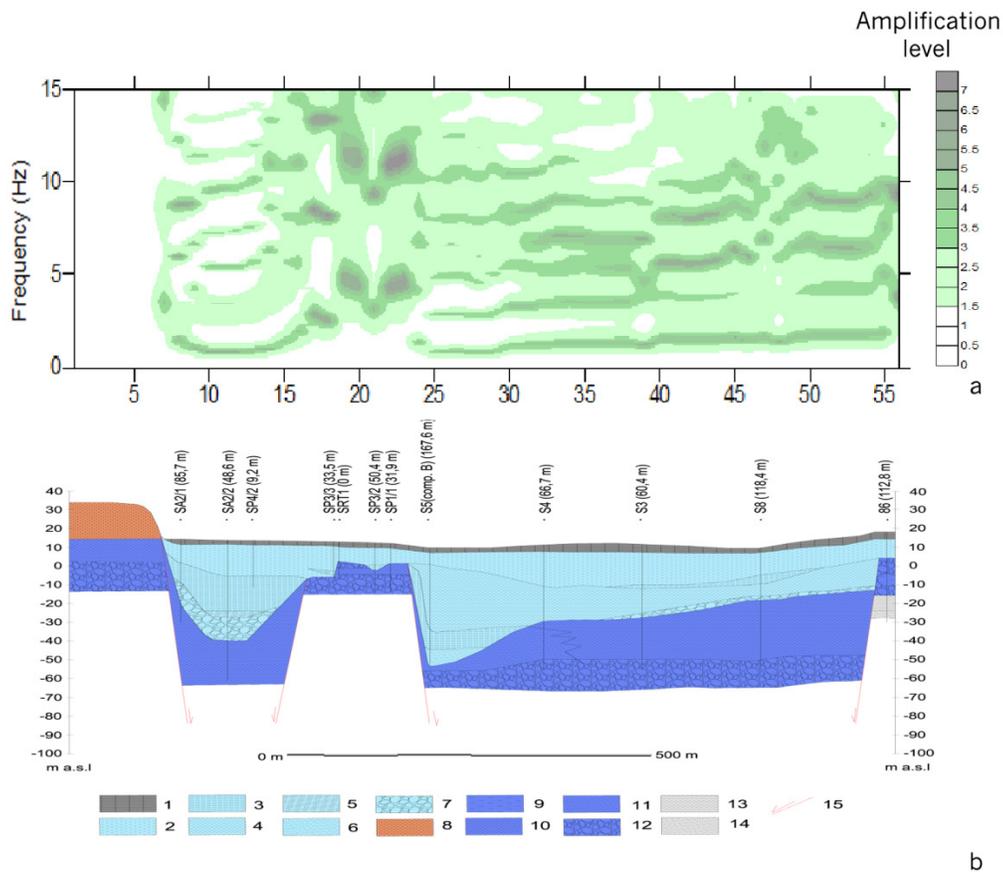


Fig. 2 - Results of the 1D numerical modeling of the 56 soil columns composing the geological cross-section FF': a) Contour map of the $A(f)$ vs distance along the section b) Geological cross-section. Legend: Recent alluvial deposits (18 ky-present): lithological units from 1 to 7. Deposits of the volcanic district of Alban Hills and of the M. Sabatini (561-360 ky): lithological unit 8. Paleo-Tiber 4 deposits (Santa Cecilia Formation) 650-600 ky: lithological units from 9 to 12. Plio-Pleistocenic bedrock “Marne Vaticane - Monte Mario - Monte delle Picche Formation”: lithological units 13-14.

The so obtained $A(f)$ distribution (Fig. 2a) is influenced by the stratigraphic effect only, i.e. related to the thickness of the alluvial deposits (including the recent alluvia and part the Paleo Tiber 4 deposits) with respect to the seismic bedrock depth, while it cannot take into account the lateral heterogeneity of the alluvial fill or the shape of the local seismic bedrock. In particular, it is worth noting that the first resonance mode ranges between 0.8 and 1.0 Hz and it remains constant for a large part of the cross section where the thickness of the alluvia varies in the range 35-65 m. On the contrary, where the thickness of the alluvia significantly decrease (down to 15-20 m), due to the local structural setting, the first resonance mode increases to higher frequency values (2.0-4.5 Hz). The higher resonance modes are related to the different seismo-stratigraphic conditions of each soil column and, in particular, to the presence of layers responsible for higher impedance contrasts.

The here obtained results should be considered as preliminary, since it is reasonable that the local seismic response in case of heterogeneous alluvial fill is influenced by 2D effects, in terms of both amplification and shear strain distribution.

Calibration of the absorbing boundary conditions for 2D fully numerical modeling

A proper 2D numerical modeling is planned to be performed through numerical codes implemented by the Institute of Paris IFSTTAR, and these codes are based on different numerical solutions, the Finite Element Method (FEM) and the Boundary Element Method (BEM). As reported in Semblat et al. (2011), the numerical analysis of elastic wave propagation in unbounded media can be difficult due to spurious waves reflected at the model artificial boundaries; this point is particularly critical for the analysis of wave propagation in heterogeneous or layered systems as in the present study. In this regard, Semblat et al. (2011) proposed an absorbing layer solution, based on Rayleigh/Caughey damping formulation that considers both homogeneous and heterogeneous damping in the absorbing layers. The efficiency of the method was tested through 1D and 2D FEM simulations, and the best results were obtained considering a damping variation up to $Q_{\min}^{-1} \approx 2$ ($\xi = 1.0$) defined by a linear function in the heterogeneous case (five layers with piecewise constant damping) and linear as well as square root function in the continuous case. This theoretical study was performed considering a model composed of a homogeneous elastic medium and an absorbing lateral layered boundary. Such an approach was not yet tested for heterogeneous deposits, i.e. characterized by vertical and lateral contacts among layers with different mechanical and dynamical properties. For this reason, the efficiency of the absorbing layers in case of highly heterogeneous deposits needs to be checked by additional numerical tests.

A new numerical model was designed according to the geometry used by Semblat et al. (2011) but introducing two horizontal and homogeneous sub-layers (Fig 3a-c). The results of the model were analyzed in order to choose the most efficient features (i.e. thickness and damping) of the absorbing layer system, and considering impedance contrasts from 1.4 up to 12.5 between the 2 horizontal sub-layers representing the physical domain of interest.

This parametric analysis was performed to evaluate the reduction of efficiency of the adsorbing layer in relation with the longest wave lengths propagated in the model, these latter functions of the maximum wave velocity of the 2 considered sub-layers.

Some preliminary results of the performed modeling are here presented for the Fosso di Vallerano case in which the two modelled sub-layers are characterized: i) by the same velocity values for the S and P seismic waves respectively (i.e. 231 m/s and 400 m/s) ii) by a different density (1800 – 2500 kg/m³ respectively); the so resulting impedance contrast is about 1.4.

The modeling was performed by the FEM CESAR-LCPC code, by applying a synthetic input characterized by a predominant frequency of 10 Hz according to Semblat et al. (2011) .

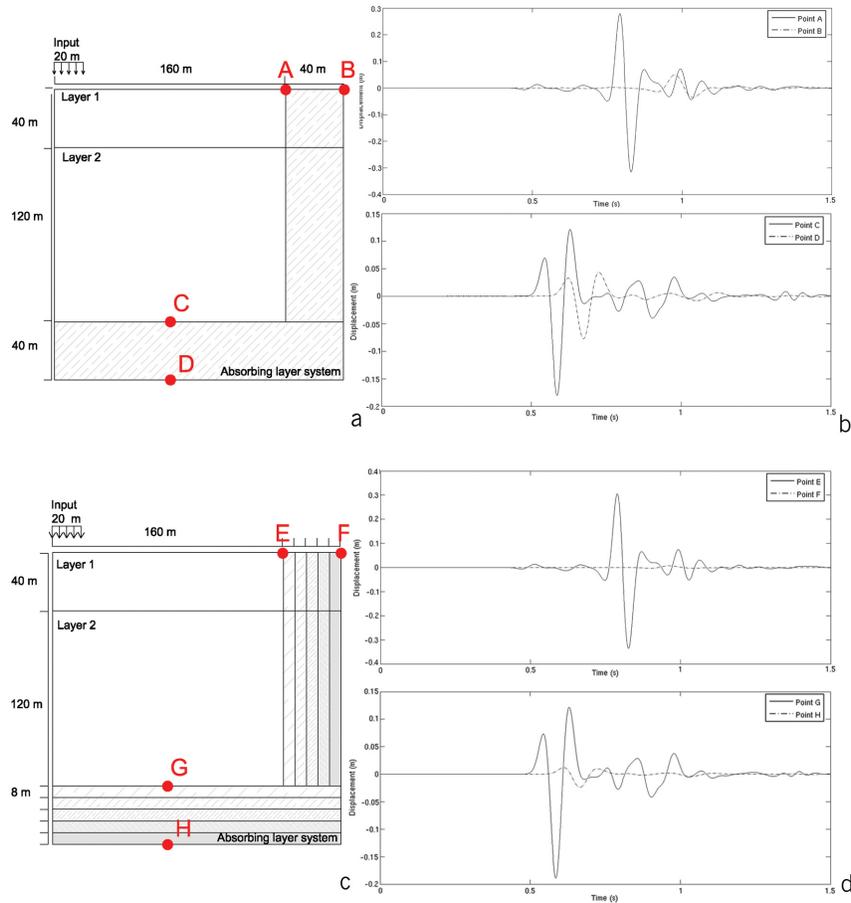


Fig 3: Efficiency analysis of the absorbing layer system in heterogeneous model: a) numerical model constructed for the HOL case; b) results, in terms of displacement, from the numerical modeling performed using HOL; c) numerical model constructed for the HEL case; d) results, in terms of displacement, from the numerical modeling performed using HEL

Two different typologies of absorbing layer system were considered, the first one corresponding to a Homogenous absorbing Layer (HOL) characterized by homogenous damping value equal to $Q_{\min}^{-1} \approx 0.5$, or $\xi = 0.25$ (Rayleigh/Caughey damping), and the second one to a Heterogeneous Layer (HEL) constituted of 5 sub-layers that are characterized by a damping linearly varying from $Q_{\min}^{-1} \approx 0.2$, or $\xi = 0.1$ (in the inner part of the absorbing layer system), to $Q_{\min}^{-1} \approx 2$, or $\xi = 1.0$ at the boundary of the numerical model.

In agreement with the results by Semblat et al. 2011, the results obtained so far demonstrate that for the heterogeneous model the HEL provides better solutions than the HOL. In particular, the results obtained by using the HOL demonstrate that the peak of the vertical component of the displacement (PGD_v) induced by the seismic input in the most external part of the absorbing layer system (point B in Fig. 3a) is equal to 18.0% (Fig. 3b) of PGD_v recorded in the inner part of the model (point A in Fig. 3a). The PGD_v in the most external part of the bottom portion of the absorbing system (point D in Fig. 3a) is equal to 35.2% (Fig. 3b) of the peak recorded in the inner part of the model (point E in Fig. 3a). These results lead to deduce that the absorbing layer system is more efficient in the lateral part of the model than in the bottom part. Analyzing the results obtained considering the HEL, it can be seen that the PGD_v in F in the Fig. 4c (most external part of the heterogonous absorbing layer system) is equal to 2.3% (Fig. 3d) of the PGD_v recorded in the inner part of the model (point E in Fig. 3c). The PGD_v in the most external part of the bottom portion of the absorbing system (point H in Fig. 3c) is equal to 9.9% (Fig. 3d) of the peak recorded in the inner part of the model (point G in Fig. 3c). Similar results were obtained analyzing the reduction of the Arias Intensity (AI) associated with the vertical component of the acceleration within the absorbing layer. In fact, in the case of the HOL (Fig. 3a) the Arias Intensity at point B is equal to 0.6% of the one at point A and at point E it is 9.0% of the one at point D. For the HEL (Fig. 3c), the AI at point F is equal to the 0.005% of the value at point E and at point H it is equal to the 0.6% of the value at point G. These preliminary results encourage further studies in order to better design the absorbing layers at the boundaries of heterogeneous models to improve their efficiency

Conclusions

Based on a high-resolution geological model reconstructed for the Fosso di Vallerano valley, a calibration of the subsoil seismo-stratigraphic was performed by considering the seismometric records of the aftershocks of the L'Aquila seismic sequence collected during the Summer of 2009.

The calibration analysis pointed out the relevant role on the local seismic response of the layering (i.e. vertical heterogeneity) of the subsoil deposits. This evidence was confirmed by a 1D model performed on 56 soil columns that discretized a geological cross section obtained along the Fosso di Vallerano valley in correspondence to the "Europarco Business Park".

In preparation for 2D numerical modeling of the valley, i.e. including the lateral heterogeneity of the alluvial deposits as well as the Site-City Interaction, a preliminary numerical experiment was performed aiming at calibrating the typology and the thickness of the absorbing layers system to reduce the presence of spurious waves reflected at the model artificial boundaries. The results obtained so far demonstrate that the best solution consists of a heterogeneous absorbing layer (HEL) system, i.e. consisting of 5 sub-layers characterized by a damping linearly varying from $Q_{\min}^{-1} \approx 0.2$ to $Q_{\min}^{-1} \approx 2$.

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