1D SITE RESPONSE ANALYSIS TO ASSESS THE SEISMIC VULNERABILITY OF TWO UNIVERSITY BUILDINGS AT L'AQUILA

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We report the results of the 1D site response modelling finalized to the seismic vulnerability evaluation of L'Aquila University buildings, named Coppito 1 and 2, located in the intramontane plain of Aterno River, which is filled by 100 m-thick Quaternary detrital deposit (mainly silt, gravel, conglomerate, breccia) (Cosentino *et al.*, 2017; Del Monaco *et al.*, 2013; Gaudiosi *et al.*, 2013; Lanzo *et al.*, 2011) (Fig. 1).

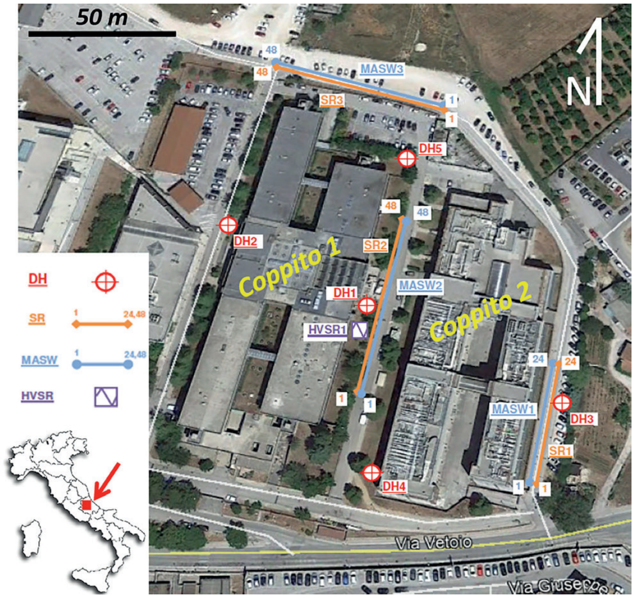

Fig. 1 - Location map of Coppito 1 and 2 buildings and the geophysical investigations (DH: down-hole test, HVSR: microtremor measurement, MASW, SR: seismic refraction survey) and boreholes performed in the studied site (DH1-5). In the borehole DH1 was carried out also the SDMT test.

A multitask approach was carried out via thorough geological, geophysical and geotechnical investigations with the aim to define the representative subsoil models of the studied area, to assign the numerical values to the parameters involved in the modelling, to select the input motions, and, finally, to perform the 1D numerical modelling with the code STRATA (Kottke and Rathje, 2008).

We recognized four seismo-stratigraphic models. The models A1 and B1 are characterized by the layer Gravel A and seismic bedrock depth at 150 m and 180 m, respectively; models A2 and B2 by the layers Gravel A and Gravel B and seismic bedrock depth at 150 m and 180 m, respectively (Tabs. 1, 2). The depth of the seismic bedrock (H), equal to 180 m, was obtained by applying the formula: $f_0 = Vs / 4H$, imposing the resonance frequency (f_0) equal to 0.8 Hz and an average shear wave velocity (Vs) of 580 m/s obtained from the HVNSR measurements and the in-hole test SDMT and DH1 performed in the studied area (Fig. 1). Conversely, the seismic bedrock depth (H) of 150 m was estimated by the empirical relationship between f_0 and H obtained for the Aterno River plain by Nocentini *et al*. (2017).

For the soil behavior the well known equivalent linear model was adopted. Thus, the shear modulus G and the damping factor D depend on the shear strain γ induced by the earthquake shaking and are iteratively adjusted until they match a fraction of the maximum strain caused in each layer by the passing shear waves. The adopted G/G_0-γ and D-γ curves of the units used for the modelling were reported in Fig. 2, the references in Tabs. 1 and 2.

As seismic input we selected three free field natural accelerograms at the bedrock, specific of the seismicity of central Italy, which were recorded by the Italian Accelerometric Netwotk: (i) 6 April 2009 (Mw: 6.1) L'Aquila earthquake recorded at the AQG station; (ii) 30 October 2016 (Mw: 6.5) Norcia earthquake recorded at the AVE station; (iii) 19 September 1979 (Mw: 5.9) Valnerina earthquake recorded at ARQ station.

The selected time histories were scaled with respect to two PGA values (0.261 g and 0.350 g). The first PGA value comes from the Italian building code for L'Aquila, under free field conditions, outcropping bedrock and horizontal topography, with a return period of 475 years according to NTC (2008). The second PGA value was proposed by Gruppo di Lavoro MS–AQ (2010) and corresponds to the return period of about 1000 years.

In the case under examination, the code STRATA was used to perform, in total, 24 analyses of local seismic response given the six seismic input motions and the four subsoil models (Tabs. 1, 2).

The code STRATA consider a half-space that refers to a continuous model formed by horizontal soil layers of infinite extent. The linear viscoelastic model refers to the Kelvin-Voigt rheological model (spring and viscous damper in parallel) in which it is assumed that the shear waves propagate vertically. The equivalent linear model treats the shear modulus G and the damping ratio D as a function of the shear strain γ. STRATA calculates G and D via iterations that are leaded by the level of deformation of the subsoil layers induced by the earthquake shaking (Kottke and Rathje, 2008).

To make easier the comparison between the results of the performed site response analysis and the Italian normative spectra (NTC, 2008), a procedure for regularizing the spectral forms was applied (Liberatore and Pagliaroli, 2014). This procedure allows to transform the calculate site seismic response spectra with the standard spectral form, according to the NTC (2008) (Fig. 3).

The main preliminary results of the seismic site response concern the evident stratigraphic effect of the studied area (1.4-1.5 values in pseudo-acceleration between output and input).

Therefore, we registered the presence of a considerable amount of energy with acceleration peaks very early with respect to the regulatory plateau, for periods completely not evaluated by the spectra of NTC (2008) (period T about 1 sec) (Fig. 3). These results, despite preliminary, can be useful for improving the seismic vulnerability assessment of the L'Aquila University buildings, considering the well-constrained subsoil models and the free field natural accelerograms related to earthquakes characterising the seismicity of the last decades occurred in central Italy.

Tab. 1 - The subsoil models **A1** and **B1** characterized by the layer “Gravel A” and the seismic bedrock depth about 150 and 180 m, respectively.

Unit	Lithology	Depth (m)	Vs (m/s)	γ (kN/m³)	G/G$_0$	D (%)
Colluvium	silt	0-6	300	20	Gruppo di Lavoro MS–AQ (2010)	Gruppo di Lavoro MS–AQ (2010)
Gravel A	gravel	6-37	400-500	20	Rollins *et al.* (1998)	Rollins *et al.* (1998)
Conglomerate	calcareous conglomerate and breccia	37-150/180	700-750	20	Modoni and Gazzellone (2010)	Modoni and Gazzellone (2010)
Limestone *seismic bedrock*	stratified detrital limestone	>150/180	1300	23	Linear elastic behavior (G$_0$=4000 MPa)	Cost = 0.5%

Tab. 2 - The subsoil models **A2** and **B2** characterized by the layers “Gravel A” and “Gravel B” and the seismic bedrock depth about 150 and 180 m, respectively.

Unit	Lithology	Depth (m)	Vs (m/s)	γ (kN/m³)	G/G$_0$	D (%)
Colluvium	silt	0-6	300	20	Gruppo di Lavoro MS–AQ (2010)	Gruppo di Lavoro MS–AQ (2010)
Gravel B	gravel	6-9	550	20	Rollins *et al.* (1998) upper G/G$_0$ e lower D	Rollins *et al.* (1998) upper G/G$_0$ e lower D
Gravel A	gravel	9-37	400-500	20	Rollins *et al.* (1998)	Rollins *et al.* (1998)
Conglomerate	calcareous conglomerate and breccia	37-150/180	700-750	20	Modoni and Gazzellone (2010)	Modoni and Gazzellone (2010)
Limestone *seismic bedrock*	stratified detrital limestone	>150/180	1300	23	Linear elastic behavior (G$_0$=4000 MPa)	Cost = 0.5%

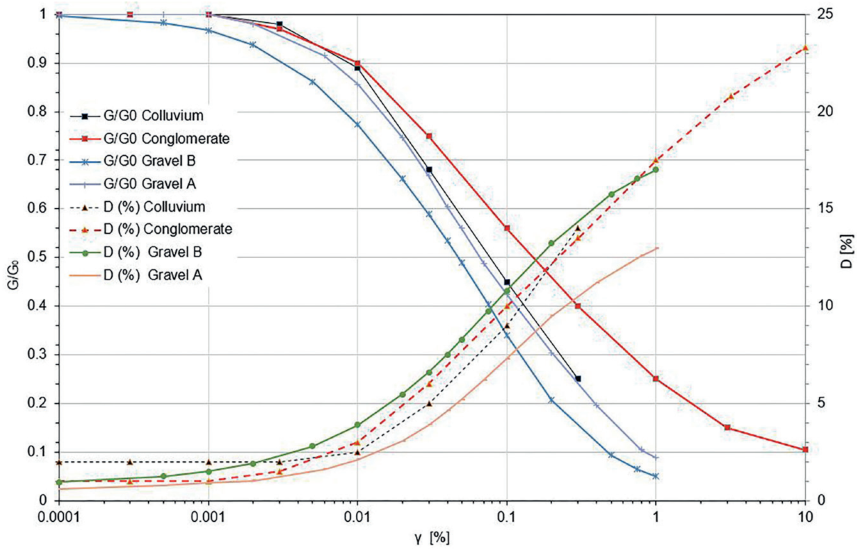

Fig. 2 - G/G$_0$-γ and D-γ diagrams used for the 1D modelling of the Colluvium, Gravel A, Gravel B and Conglomerate reported in Tabs. 1 and 2.

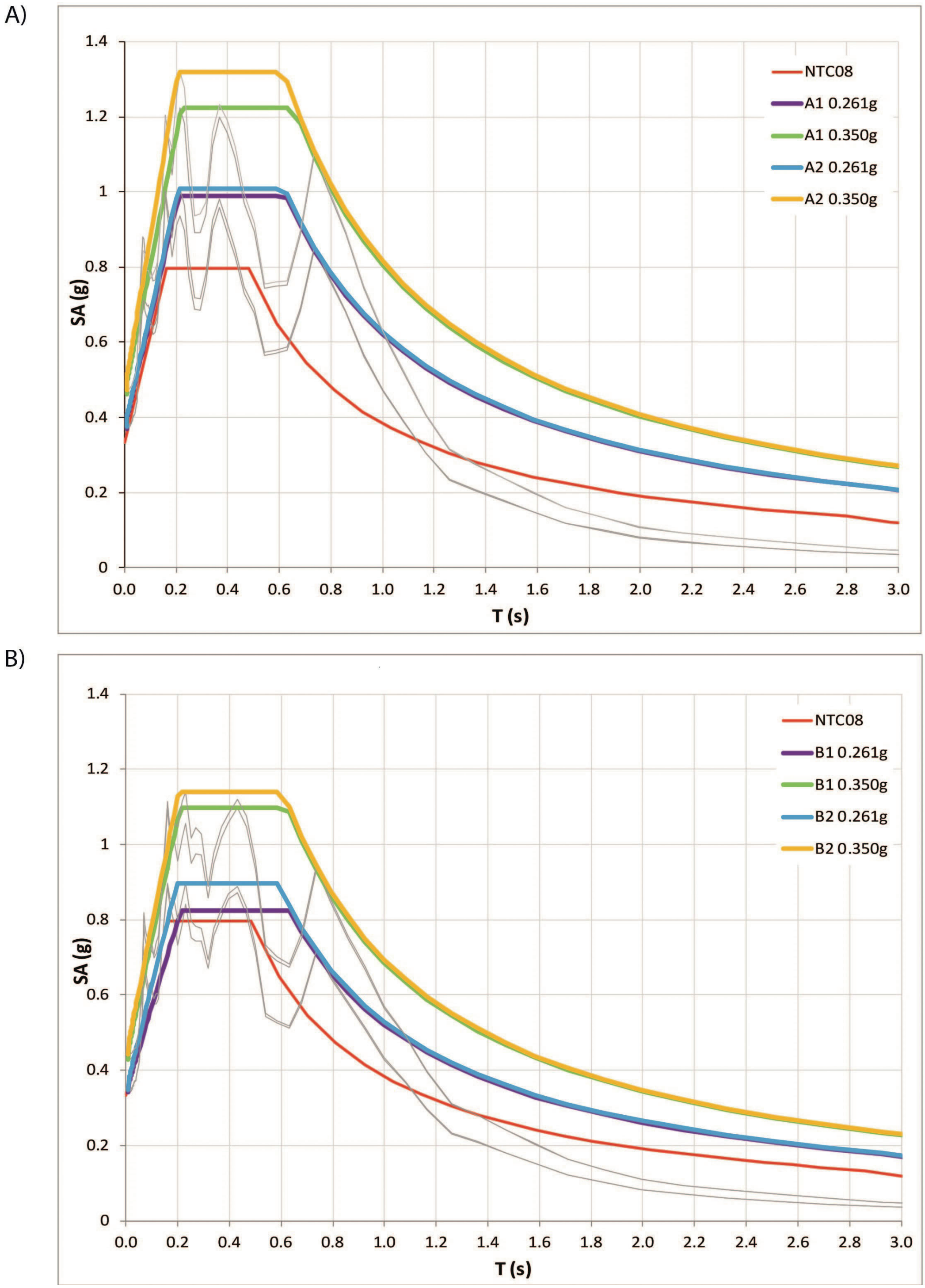

Fig. 3 - A) Seismic site response output spectra (in gray) and normalized spectra (colored) for A1 and A2 subsoil models and scaled input accelerograms (PGA: 0.261 g and 0.350 g). B) Seismic site response output spectra (in gray) and normalized spectra (colored) for B1 and B2 subsoil models and scaled input accelerograms (PGA: 0.261 g and 0.350 g). The output and normalized spectra are compared with the SLV (limit state of life safeguard) spectrum for the studied site according to the NTC (2008) (in red).

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