SEISMIC GROUND RESPONSE ANALYSIS AT THE SITE OF SAN FELICE CHURCH IN POGGIO PICENZE

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ABSTRACT

When the seismic waves travel from the bedrock to the ground surface a seismic amplification can occur due to the local conditions at a specific site. Lithostratigraphic amplification is typically evaluated using deterministic analyses, which do not allow assessing the uncertainty associated with the computed ground motion due to the aleatory nature of soil model parameters and the variability of seismic input. The ground motion amplification at the site of San Felice church, a historical stone structure located at PoggioPicenze (L’Aquila, Italy), has been investigated using a fully stochastic-based procedure. The seismic geotechnical characterization of the site was based on field geological mapping and drilling and geophysical tests from previous investigation campaigns. The lithostratigraphic amplification effects at San Felice church site was assessed through 1D stochastic site response analyses using for the object motion 7 real records, consistent with the regional seismotectonic setting and compatible to the Italian code-based spectrum referred to 475-year return period. The results obtained from 1000 numerical simulations have been expressed in terms of mean elastic acceleration response spectrum and its associated uncertainty and acceleration time histories computed at the basement of San Felice church.

INTRODUCTION

The 6th April, 2009, a 6.3 Mw earthquake hit the L’Aquila region (Italy, see Fig. 1) and caused damage to structures over an area of approximately 600 km². The number of fatalities was 308, more than 1500 people were injured and more than 65000 were evacuated. The macroseismic intensity value at L’Aquila center was reported varying between VIII and IX (MCS). Damages were even more significant in some villages located in the middle Aterno valley, where intensities as high as IX-X were experienced in Castelnuovo and Onna. In total, 14 municipalities experienced a MCS intensity between VIII and IX, whereas those characterized by MCS intensity I≥VII were altogether 45[1]. The results presented here, which are based on the full report at Tarque et al. [2], focuses on the assessment of possible amplification effects, through one-dimensional (1D) stochastic analysis, of the ground motion due to the specific lithostratigraphic conditions at San Felice church in PoggioPicenze, a small village located along an intermontane basin of the central eastern Apennines (Fig. 1), about 17 km far away from L’Aquila town (Abruzzo region). The procedure to carry out stochastic ground response analysis is explained in following sections. Each of these steps has

Figure 1. Location map of the study area (white square) within the Apennines chain

Definition of the reference seismic input
The reference seismic action at the site of San Felice church has been represented by uniform hazard acceleration spectra and natural acceleration time histories. In Italy, the probabilistic seismic hazard was assessed by the National Institute of Geophysics and Volcanology (http://esse1.mi.ingv.it/). The results of this study were adopted by the current Italian building code [3] to prescribe the design seismic action. However, the definition of the level of severity of the seismic input (represented for instance by the return periods), to be used for ancient monumental structures, such as the San Felice church, is a rather tricky issue that is often debated by specialists worldwide. For this work, the 475-years return period has been selected.

A set of 7 real, spectrum- and seismo-compatible accelerograms, recorded at outcropping rock sites with flat topographic surface, was downloaded from the SEISM-HOME web portal (http://www.eucentre.it/seismhome.html; [4]). Fig. 2 shows the elastic acceleration response spectra of the 7 selected natural accelerograms.

Figure 2. Elastic acceleration response spectra of the 7 natural accelerograms for the 475 year return period (damping ratio 5%) obtained from SEISM-HOME

These records are spectrum-compatible with the acceleration response spectrum prescribed by the Italian building code [3] at the site of San Felice church and are also consistent with the regional seismotectonic and seismogenic setting of the area, where the site under investigation is located. The selected accelerograms have magnitudes that range from 6 to 6.93, and epicentral distances that vary from 11 km to about 94 km. Their scaling factors range from 0.43 to 2.83, with a mean of 1.57.

Geological and geomorphological setting of the study area have been studied since the beginning of last century, and recently after the 2009 earthquake, focusing on tectonics, stratigraphy and Quaternary continental deposits [9] [10] [11] [12]. The PoggioPicenze area is located at the boundary of the Paganica-San Demetrio basin, an intermontane basin filled with an up to >200 m thick Quaternary alluvial and lacustrine succession. Such tectonic basin is part of the middle Aterno River Valley, composed of a complex arrangement of several, laterally linked, NE-SE elongated fault-bounded sedimentary basins connected with a regional extension phase that affected the Central Apennines since Late Pliocene [8] [12] [13]. The area is affected by a strong seismicity as documented by several historical and early instrumental earthquakes [14], generally attributed to the main recent faults active in the area (and particularly to the Paganica faults [7]). Main earthquakes are: the 1461 event (Mw 6.4), the 1703 multiple event (Mw 6.7), and then the
1762 (Mw 6.0), 1791 (Mw 5.4), 1916 (Mw 5.1) and 1958 (Mw 5.2) events [6]. More in general repeated strong earthquakes in the area are testified also by paleoseismological evidences [15]. A geological map was realized by means of field mapping and borehole analysis. It shows the distribution of Quaternary continental deposits (i.e. colluvial deposits, alluvial fan deposits, fluvial and lacustrine deposits; Fig. 4a) in the PoggioPicenze area. For geotechnical information and geophysical field investigation, drillings and geophysical tests retrieved from previous investigation campaigns have been collected in order to investigate the soil profile in the studied zone. The tests give just information about the first 30 m of the fluvial and lacustrine deposits (see 5a layer in Fig. 4b). Any tests reached the depth of the bedrock. These lacking information was indirectly overcome by detail field geological mapping of the surrounding areas and the correlation with existing subsurface data. In summary, four general layers are identified down the church (also described in Table 1): conglomerate (4b in Fig. 4b), white calcareous silts (5 in Fig. 4b), breccia and conglomerate (6 Fig. 4b) and bedrock (7 in Fig. 4).

Figure 4. a) Geological map of PoggioPicenze area. Quaternary continental deposits: 1) backfill deposits; 2) recent colluvial deposits; 3) ancient colluvial deposits; 4) alluvial fan deposits (a: upper part, b: lower part); 5) fluvial and lacustrine deposits (a: upper part, b: lower part); 6) slope deposits. Bedrock (Meso-Cenozoic marine succession): 7) limestones. Symbols: 8) inferred fault; 9) borehole and geotechnical investigations; 10) geophysical field investigations; 11) geological profiles; 12) interested site. b) Stratigraphic and lithologic scheme of the PoggioPicenze area [16].

Statistical characterization of the soil profile Proper interpretation of the available data (as MASW, geoelectric tomography surveys, SPT and down hole tests, not reported here) led to the definition of a geotechnical model at the San Felice church site to be used for ground response analyses. To first approximation, the site under investigation was modelled as a sequence of constant thickness, plane and parallel layers corresponding to a 1D soil stratigraphy. To define such a geotechnical model for ground response analysis, it was necessary to define the number of layers and then, for each layer, the following parameters: thickness, shear wave velocity, total unit weight of soil and shear modulus and damping degradation curves. At last the values of shear wave velocity and of total unit weight for the half-space are required. The properties of the adopted soil profile are specified in Table 1. The log profile showed in Fig. 5 indicates the Quaternary continental deposits conformed by Conglomerates up to 5 m (alluvial fan deposits are present at top); calcareous silts pertaining to fluvial and lacustrine deposits up to 25-30 m; grey clayey silts up to 20 m; Calcareous breccia (5- 8 m); the bedrock at a not well defined depth (at least >60-70 m).

Table 1. Proposal soil profile for the study zone and its mean values. Numbers of second column refer to Fig. 4 and 5
perform ground response analyses at the site. Since the gathered data did not directly give this information, it was necessary to compute basing on available data the standard deviation values (σ) taking into consideration some assumptions as illustrated in details in Tarque et al. [2]. The uncertainty associated to each geotechnical parameters has been quantified in terms of coefficient of variation (CoV). In the stochastic ground response analyses, the CoV was approximated to the value of 15% for the thickness (h) and the shear wave velocity (Vs) of each layer and 5% was assumed for the unit weight (γ). The degradation curves for shear module and damping were obtained from Table 4.1 of Working Group MS-AQ [17] where some soil tests were performed for PoggioPicenze.

Stochastic site response analysis In Matlab (http://www.mathworks.com), following a Monte Carlo simulation, 1000 soil profiles (Fig. 6) were generated for the area under investigation with the Latin Hypercube sampling technique. The soil properties used for the stochastic analysis (see Table 1) were assumed to follow a Normal distribution. The minimum and maximum value of Vs, thickness and unit weight were in the interval of ± three standard deviations. Then, an input file (*.txt) was automatically written to be used with Shake91 (software developed by Schnabel et al. [18]), which implements a linearequivalent constitutive model for soils, coupled with a 1D soil stratigraphy. The input accelerograms for each of the 1000 analyses was randomly selected from the set of 7 natural accelerograms following a Uniform distribution.

CONCLUSION

The PoggioPicenze village is located in a very complex geological sector within the L’Aquila tectonic basin. It is characterised by calcareous and calcareous-marlyMesozoic bedrock and by widespread Quaternary continental deposits, and it is affected by a strong seismicity documented by paleoseismological studies, historical earthquakes and instrumental seismicity. The integration of surface field geological and geomorphological mapping and subsurface geological, geotechnical and geophysical investigations allowed for the assessment of a complete soil profile below the PoggioPicenze area with particular reference to the San Felice church site. The features (type, thickness, Vs, γ) of the main layers was defined from the buried calcareous bedrock (at a depth of >60-70 m) to a thin layer of buried breccia and conglomerate, to a thick multiple layer of grey to whitish clayey to calcareous silts, with sandy and gravel lenses, to the top thin conglomerate layer.


