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CHARACTERIZATION OF CODE SOIL PROFILES FOR TERCEIRA ISLAND (AZORES, PORTUGAL)

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The Azores Archipelago is located in the Atlantic Ocean, near the Triple Junction of Eurasia, North America and Africa plates. The Islands, aligned in WNW-ESE direction, cross the Middle Atlantic Ridge (MAR) and are divided into three groups according to their geographical distribution: Flores and Corvo (Western Group) rest on the American Plate, while Terceira, Graciosa, S. Jorge, Pico and Faial (Central Group) and S. Miguel and Sta. Maria (Eastern Group) lie on Eurasian and/or African Plates. The tectonics and location of the border between these two latter plates has been subject of discussion, for several years, in the scientific community (Laughton et al. 1972; Fernandes et al. 2006; Borges et al. 2007).

Due to their particular location the Central and Eastern Groups exhibit high seismic and volcanic activities. Since its discovery, in the XV century, the islands suffered the effects of several seismic events, mostly moderate main shocks and seismic swarms but, sometimes, major tectonic destructive events of larger magnitude occurred. The last major earthquake took place on January 1st, 1980 (M=7.2), caused more than fifty deaths, hundreds of injuries and thousands of homeless and produced great damage in Angra do Heroísmo (Terceira's capital with 21,300 inhabitants). The most recent destructive earthquake occurred on July 9th, 1998 (M=6.0) close to Faial Island, caused eight deaths and hundreds of homeless affecting Pico, Faial and S. Jorge islands. For both earthquakes the maximum intensity felt was VIII (Mercalli modified intensity, MMI).

In the seismic hazard zonation of Portugal (Carvalho, 2010), S. Miguel, Terceira, S. Jorge, Faial and Pico Islands are located in the highest risk zone. In the Eurocode 8 (EC8) Portuguese rules (IPQ, 2010), a particular classification for the Azorean volcanic soils is presented. Five soil profiles were identified, based on available geotechnical and geophysical studies (Malheiro and Nunes, 2007). Mean shear-wave velocities, for each profile, are also provided for Vs30 estimation.

However, the volcanic origin of the geological formations produces large variability on these profiles (similar soil profile but with different layers thickness due to the occurrence of several volcanic episodes with different types and different magnitudes with different time durations). With the objective to contribute for a better characterization of the seismic behaviour of the Azorean soils, we present the results of 1D earthquake response analysis performed using equivalent linear method (Schnabel et al., 1972), as it is implemented in the ProShake (n.d.) software, for some sites in Terceira island. In order to take into account the soil non-linear behaviour, we used modulus ratio and damping ratio curves adapted from literature (Seed and Idriss, 1970) according to the composition of the layers.

Experimental soil profiles, associated with the code profiles, were defined from the analysis of boreholes and other geological and geophysical studies (Nunes et al., 2001; Teves-Costa and Veludo, 2013; Lopes et al., 2013). Shear-wave velocities and densities, for each layer, were also estimated by

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compiling results from previous studies (Forjaz et al., 2001; Lopes, 2005; Malheiro and Nunes, 2007; Teves-Costa et al., 2009). Several input motions, with different characteristics were selected (Table 1): two local earthquakes recorded in the Azores (Vilanova et al., 2009), three strong motions from USA earthquakes (ProShake, n.d.), three synthetic accelerograms to simulate the motion produced by the 1980 and the 1998 earthquakes, as well as by a closer source associated to historical events (Veludo et al., 2013). These last motions were computing using non-stationary stochastic simulation of strong ground motion based on European records (Berge-Thierry et al., 2003; Pousse et al., 2006).

Table 1. Selected input motions

Motion	Magnitude	Epicentral Distance (km)	Peak Ground Acceleration (g)	Earthquake
M40D16	4.0	16	0.01	2001.07.06
M49D12	4.9	12	0.28	1973.11.23
Topanga	6.7	15	0.33	1994 Northridge
Petrolia	7.0	24	0.42	1992 Cape Mendocino
Taft	7.4	42	0.19	1952 Kern County
M72D45	7.2	45	0.07 / 0.12	Simulated
M65D15	6.5	15	0.25	Simulated
M55D06	5.5	6	0.16 / 0.18	Simulated

Figure 1 shows the results obtained for Escola site (in Angra do Heroísmo). This site is located close to the transition between code soil profiles 2 and 5 (PF2 and PF5). The definition of the soil profile at this site was performed according to geological information and with the results obtained from ambient vibrations array measurements performed in 2008, using high resolution frequency-wave number analysis (Wathelet, 2005; Teves-Costa et al., 2009). This led to a soil profile close to the code soil profile 5 (the softest code profile).

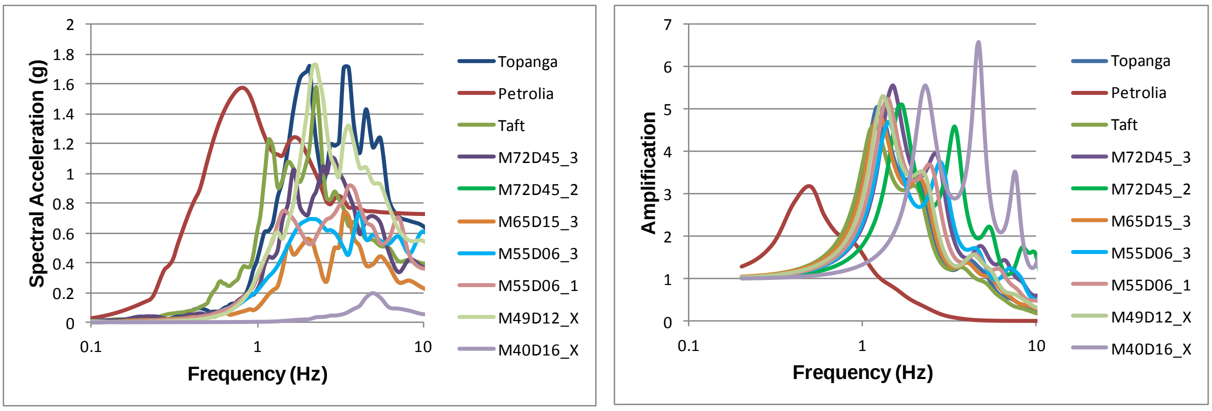

Figure 1. Left: Spectra of the motions at surface. Right: Transfer functions obtained for the soil profile at Escola site (in Angra do Heroísmo)

From the analysis of figure 1 it is possible to see the non linear behaviour effect. For almost all input motions the transfer functions indicate a fundamental frequency between 1.2 Hz and 1.7 Hz, with an amplification factor close to 5. For the weaker motion (M40D16) the obtained transfer function exhibit the fundamental frequency 2.3 Hz, with an amplification factor of 5.6. With the larger motion (Petrolia), the computed fundamental frequency is 0.5 Hz and the amplification factor is 3.2. Excluding these two extreme motions, the results are very consistent. It should be also noticed that the fundamental frequency obtained from ambient vibration measurements was 1.2 Hz (Veludo et al., 2010).

This is only an example of the results. On all 10 tested sites in Terceira Island, the non linear behaviour is well reproduced for the 4 types of soil identified (PF1, PF2, PF3 and PF5). The seismic response of PF5 profiles is distinct. However some “overlap” happens on the seismic response of PF1 and PF2 profiles, and PF2 and PF3 profiles. PF4 profiles were not identified in this island.

The purpose of this study is to give additional parameters to characterize each soil profile, namely a fundamental frequency band and an amplification range. Also it should be checked if the fundamental frequency can be estimated using ambient vibration measurements. This study will be extended to other Azorean Islands, in particular, to sites where the code soil profile 4 is identified.

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