Determination of vulnerability indexes for buildings and infrastructures designed to protect the territory of Ferrara from flood
- Part a -

Final Version

Deliverable Number D.3.3.2.

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Project Title	Preventing, Managing and Overcoming natural-hazards risk to mitiGATE economic and social impact
Priority Axis	2: Safety and Resilience
Specific objective	2.2: Increase the safety of the Programme area from natural and man-made disaster
Work Package Number	3
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Table of content

1. Introduction

Cona is part of the Municipality of Ferrara and plays an especially important role in the Ferrara territory, since it hosts the main city hospital. Seismic microzonation of the Cona area has been carried out, within the broader framework of the seismic microzonation of the whole Ferrara territory, by the Municipality of Ferrara in collaboration with the Department of Engineering of the University of Ferrara, in agreement with the most recent italian codes (O.P.C.M. 3274/2003, D.M. 14/09/2005, D.R. 102-2007, D.M. 14/01/2008, I.C.M.S. 2009). The main activities can be summarized has follows:

1. Definition of the seismic hazard for the municipality of Ferrara;
2. Geologic and geomorphologic classification of the area under study;
3. Collection of previous geotechnical and geophysical investigations;
4. Planning and implementation of 14 static penetrometric tests with seismic piezocone (SCPTU), 39 measures of environmental noise with the Horizontal to Vertical Spectral Ratio methodology (HVSR), 4 measures of the propagation speed of surface waves by means of the Extended Spatial Auto Correlation (ESAC) technique;
5. Creation of a database containing the collection of all geognostic data obtained;
6. Litostratigraphic interpretation of 643 static penetrometric tests with mecanical head (CPT), with electric head (CPTE), with piezocone (CPTU), with seismic piezocone (SCPTU) and 59 boring tests;
7. Interpretation of 99 geophysical tests (HSVR, ESAC);
8. Definition, for every penetrometric test, of the reference geotechnical profile and the principal mechanical parameters.
9. Seismic classification and evaluation of the seismic amplification factor;
10. Assessment, for every penetrometric test, of the liquefaction hazard;
11. Assessment, for every penetrometric test, of ground vulnerability to earthquake-induced settlements.
12. Estimate of the local seismic amplification for 11 locations.

2. Area description

The municipality of Ferrara covers a total surface of 405.16km2 and is depicted in Fig. 1. Cona, depicted in Fig. 1 by a red circle, is located 10km east of the city center and its territory comprises the villages of Cocomaro di Cona, Codrea and Quartesana.

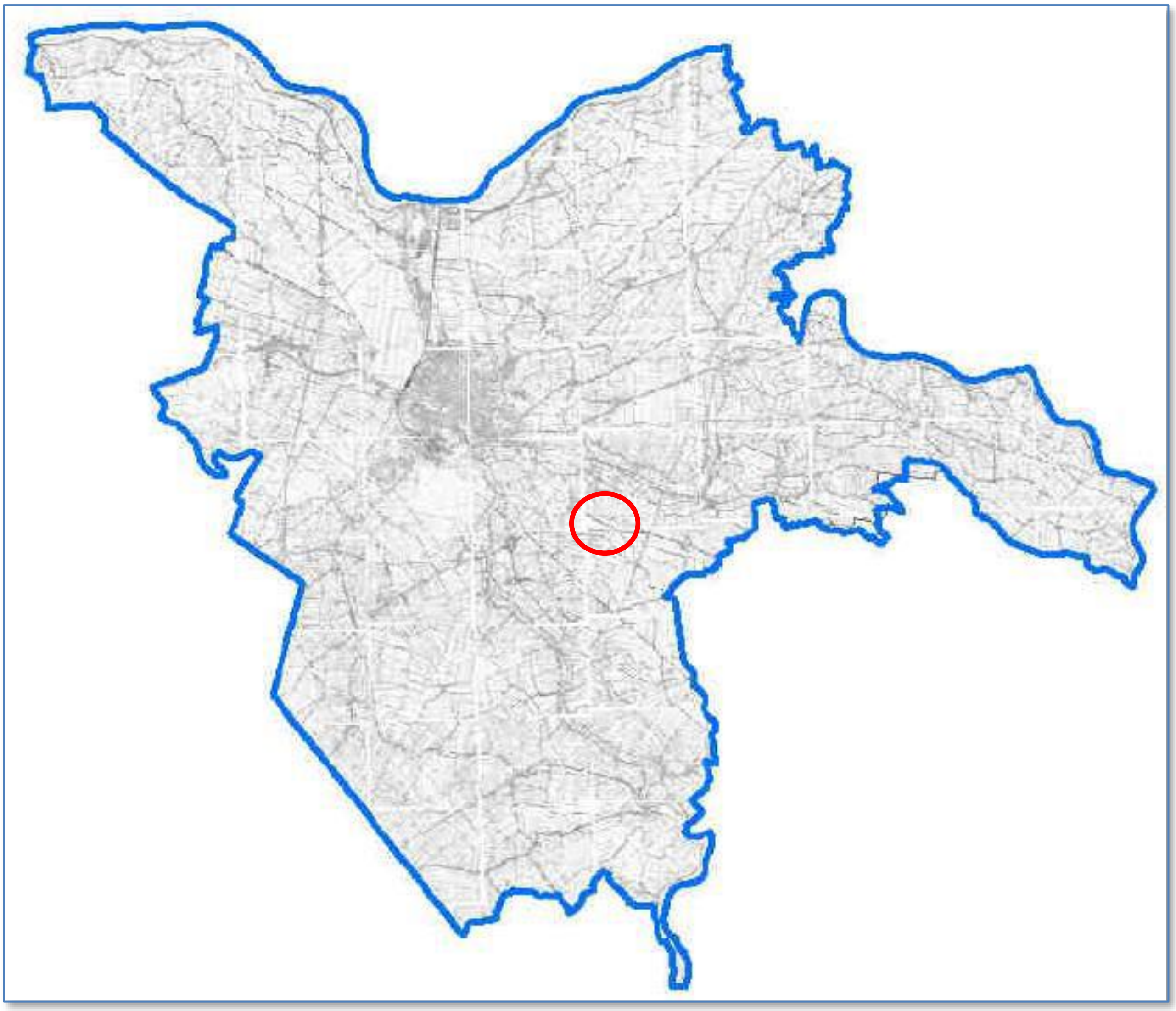

Figure 1 – The municipality of Ferrara with the Cona area in evidence

3. Seismic hazard description

The territory of the municipality of Ferrara falls within zone 912 of the seismic zonation ZS9, as represented in Fig. 2. The maximum expected magnitudo is M = 6.14. This value has been assumed as a reference value in the analyses that follow. The territory of Ferrara was struck by destructive earthquakes in May-June 2012, with two main sequences on May 20-29 with magnitude M 5.9 and 5.8, respectively. Maximum recorded horizontal accelerations were less than 0.1g.

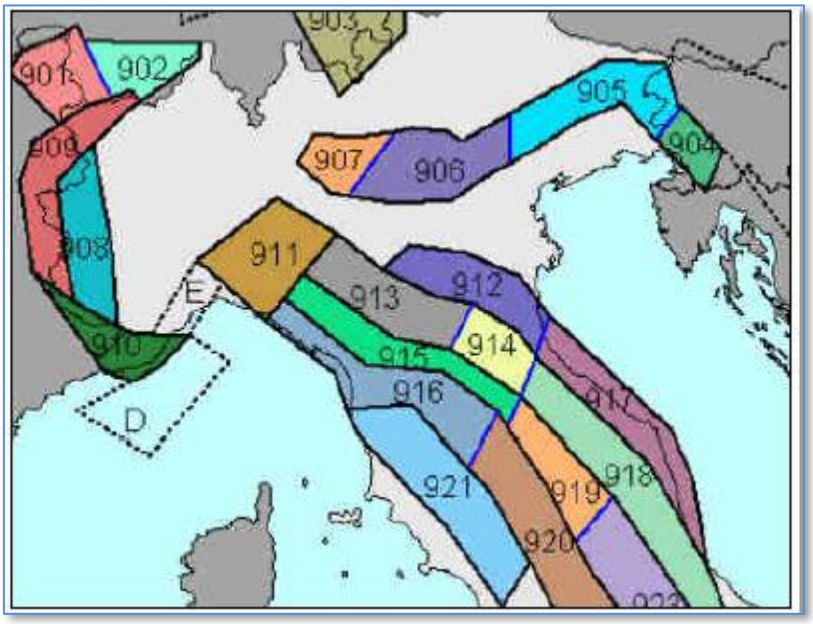

Figure 2 – Seismic zonation ZS9

The design seismic accelerations, provided by the Italian Building Code (NTC2008), are reported in Fig. 3 in terms of peak ground acceleration expected on a rigid soil (PGA_0) on a return period Tr = 475 years.

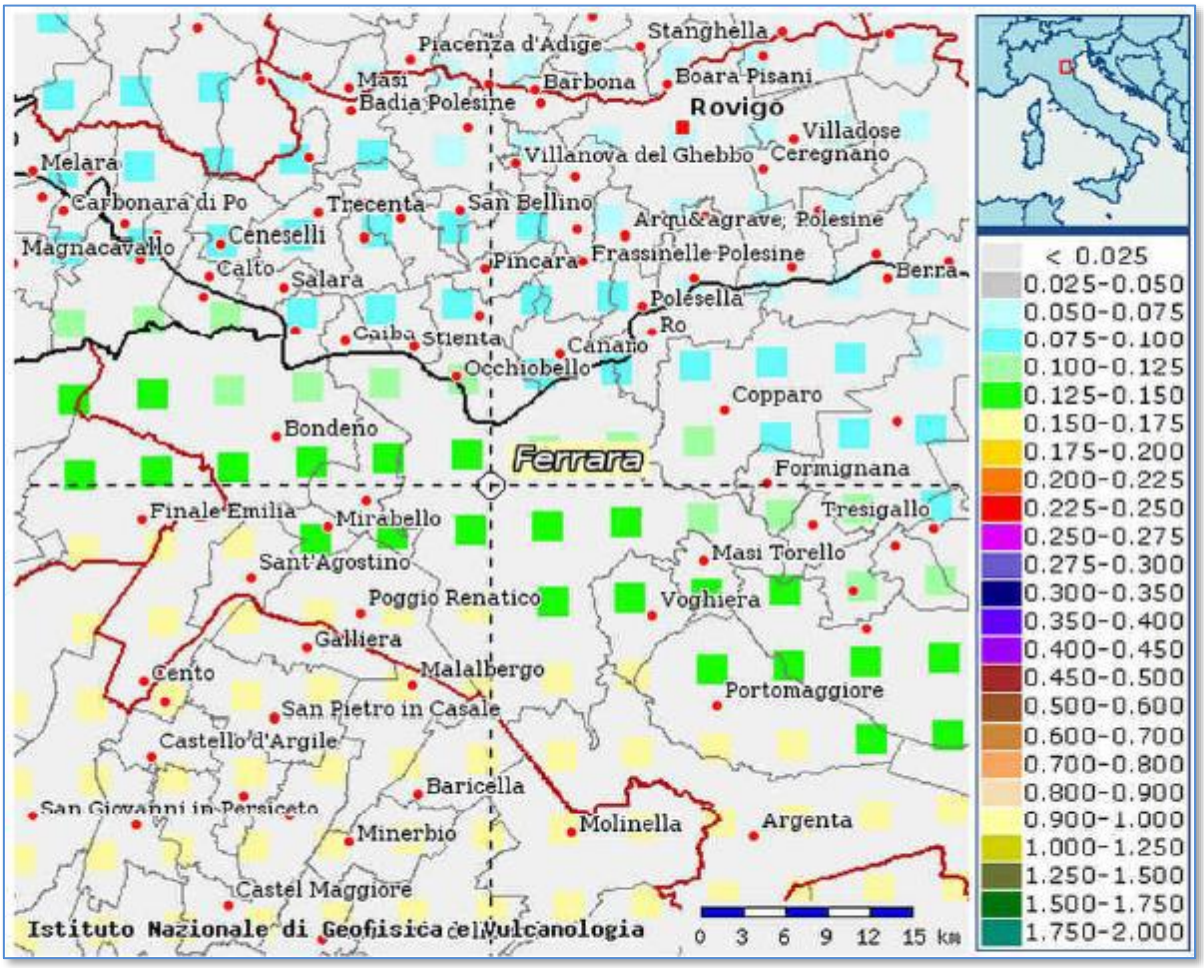

Figure 3 - Maximum peak ground accelerations expected on a rigid soil for the municipality od Ferrara

In particular, for the determination of the local seismic response, we used the reference accelerograms provided by the "*Guidelines for the seismic microzonation studies in the Emilia-Romagna region for urbanistic and territorial planning*", represented in Fig. 4. Such signals are representative of the expected ground motions on a reference bedrock soil. The fundamental parameters of such ground motions are reported in Tab. 1.

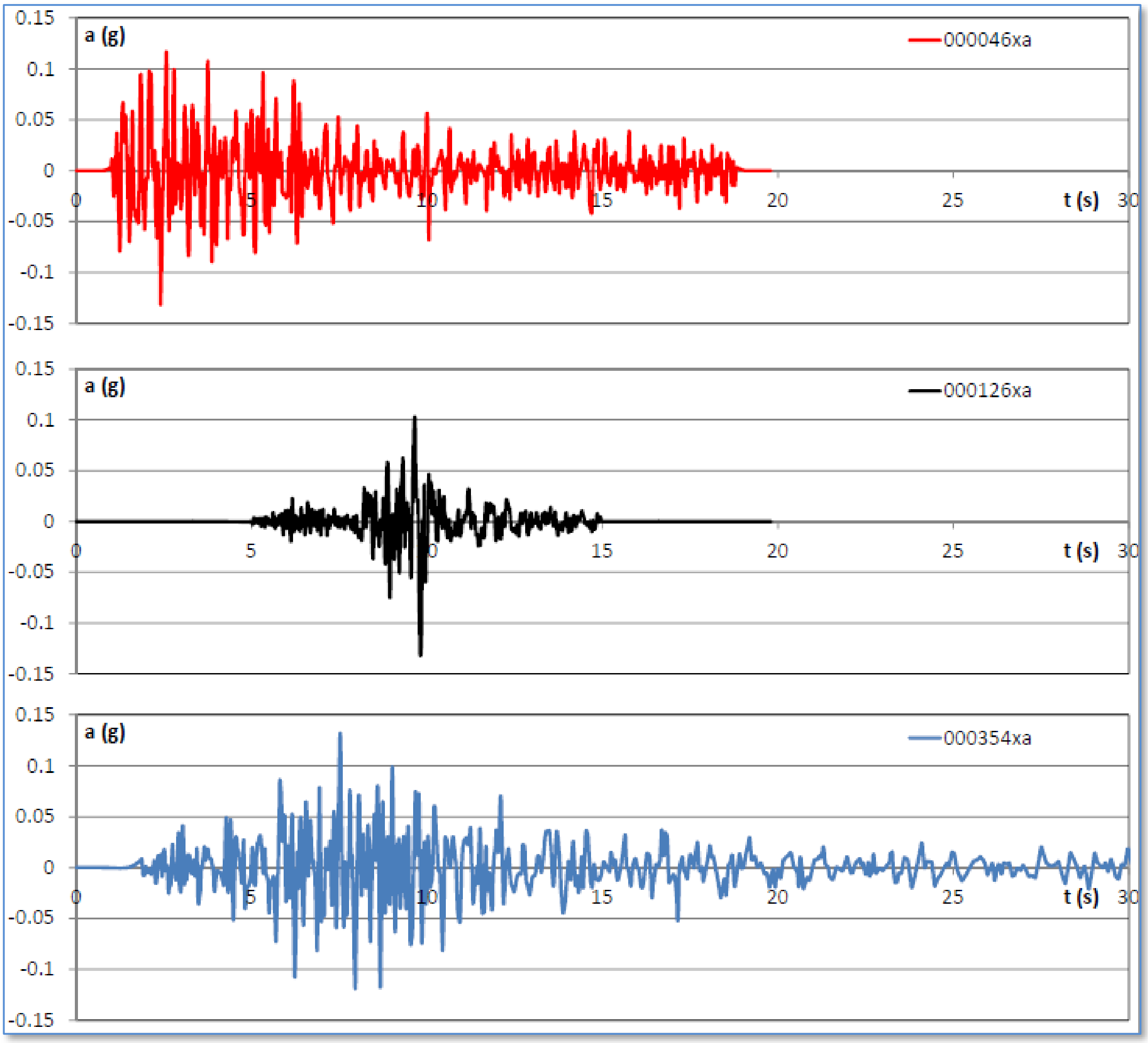

Figure 4- Reference accelerograms used for the determination of the local seismic response

codice	PGA [g]	PGV [m/s]	PGD [m]	d_{90} [s]	I_a [m/s]	SI [m]	SI_{05} [m]	SI_{15} [m]
000046xa_038008	0.132	0.060	0.006	13.480	0.197	0.168	0.048	0.094
000126xa_038008	0.132	0.075	0.006	3.525	0.054	0.180	0.045	0.096
000354xa_038008	0.132	0.065	0.014	15.355	0.212	0.279	0.048	0.143

Table 1 – Fundamental parameters for the reference ground motion adopted

4. Geomorphology of the area

The territory of the municipality of Ferrara is contained in the Po valley, a tectonic depression formed between Alps and Apennines mountain ranges. The area is located along the so-called “Pieghe Ferraresi”, arches of the orogenic belt of the Apennines made of two anticline folds oriented northward and elongated in the WNW-ESE direction. In the first 25-30m of depth in the ground, three main morphological environments can be detected:

- Paleochannel environment: is made of sands and fine grain soils.
- Interfluvial basin environment: is composed of sediments with a prevalence of fine grain soils.
- Transition environment: is made of an alternation of fine grain soils with thin layers of sands.

Groundwater level is always close to ground level, with excursions in the range of +/- 1m.

5. Subsoil model in the Cona area

5.1 Natural frequencies of the deposits

From the HVSR tests, all HVSR curves are characterized by the presence of two maxima in extra-low (0.25 Hz) and low (0.7 – 1.1 Hz) frequency, respectively.

5.2 Shear waves propagation speed from SCPTU tests

SCPTU measured shear waves propagation speed is 194 m/s. The Italian Building Code (NTC2008) assigns to the area soil cathegory C.

5.3 Shear waves propagation speed from ESAC tests

ESAC tests for the Cona area are reported in Fig. 5.

5.4 Exposure to liquefaction

Differently from the rest of the municipality, the Cona area is not subjected to liquefaction hazard.

5.5 Lithostratigraphic sequence

The adopted lithostratigraphic sequence has been summarized in Tab. 2, in terms of lithology, soil density and shear waves propagation speed.

6. Seismic microzonation of the Cona area

The local seismic response analysis has been conducted by means of the ProShake analysis software.

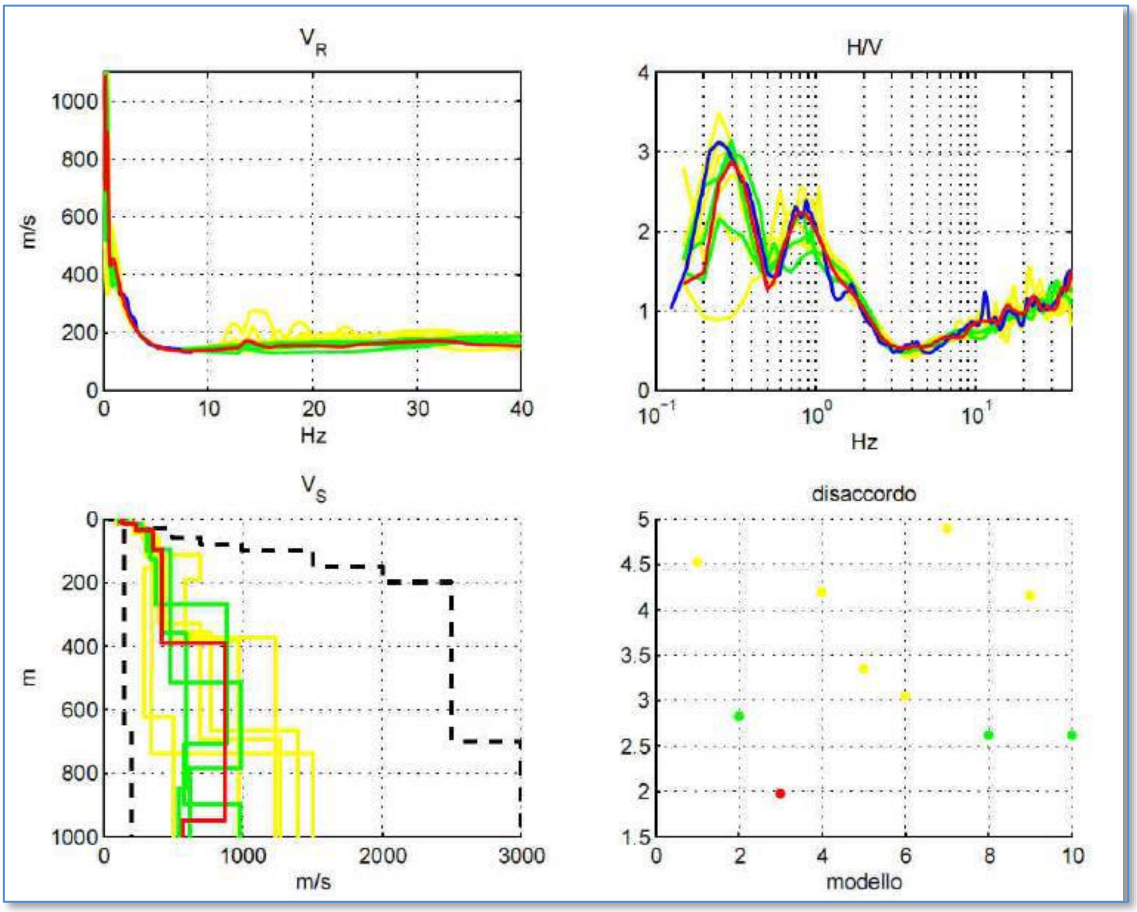

Figure 5 - ESAC tests results in the Cona area.

Table 2 - Cona lithostratigraphic sequence

Ospedale Cona				
z da [m]	a [m]	LITOLOGIA	γ_n [kN/m^3]	V_S [m/s]
0	6	L	18	120
6	16	A	18	150
16	30	A	18	225
30	35	A	18	270
35	50	S	18	360
50	65	S	18	440
65	85	A	18	470
85	120	S	18	665
120	140	A	18	730
>140		S	20	800

ProShake allows to simulate the one-dimensional propagation of the seismic motion in soil deposits horizontally stratified. ProShake works in the frequency domain transforming, by means of an FFT algorithm, an input time history sequence into the sum of harmonic oscillations with different frequencies. The nonlinear dissipative behavior of the soil is accounted for by means of an equivalent linear approach. The input of the program can be synthesized as:

i) Lithostratigraphic sequence, summarized in Tab. 2.
ii) Initial shear stiffness G_0 for each soil layer, computable from the shear waves propagation speed V_s as $G_0 = \rho_n V_s$, where ρ_n is the soil density.
iii) Shear stiffness decay curves G(γ) for each soil layer. Such curves have been determined from resonating column (RCTS) tests.
iv) Input accelerograms, depicted in Fig. 3 and summarized in Tab 1.

6.1 Computed ground motion parameters

The parameters of the computed ground motions are reported in Tab. 3.

Table 3 - Computed ground motion parameters

codice	PGA [g]	PGV [m/s]	PGD [m]	d_{90} [s]	I_a [m/s]	SI [m]	SI_{05} [m]	SI_{15} [m]
000046xa_038008_ampl	0.225	0.170	0.018	13.260	0.650	0.446	0.105	0.265
000126xa_038008_ampl	0.299	0.163	0.021	3.440	0.235	0.507	0.106	0.296
000354xa_038008_ampl	0.228	0.159	0.023	18.740	0.908	0.679	0.108	0.397

6.2 Pseudo-acceleration response spectra

The corresponding pseudo-acceleration spectra, determined from the local seismic response analysis, are reported in Fig. 6.

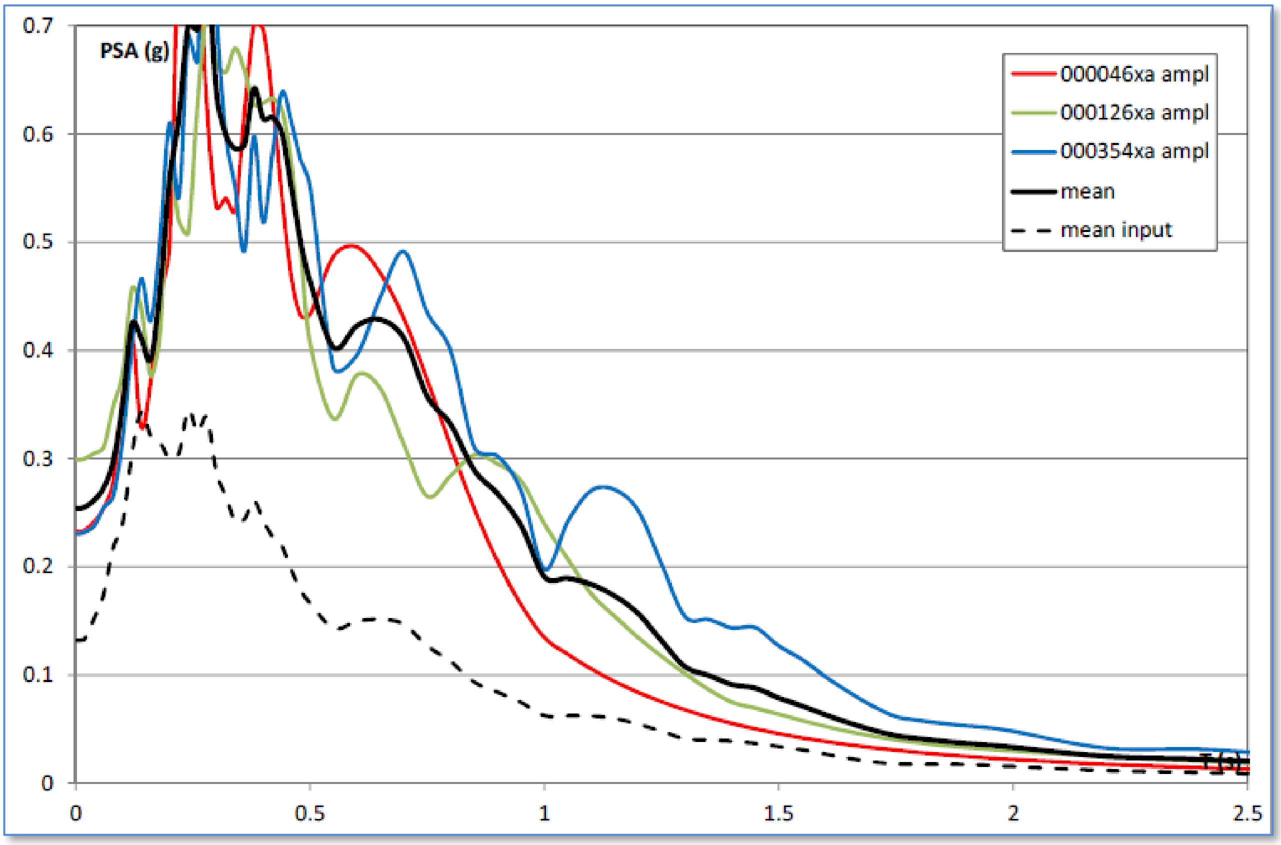

Figure 6 - Pseudo-acceleration spectra for the Cona area obtained from the local seismic response analysis.

6.3 Ground motion amplification factors

Finally, the amplification factors computed from the local seismic response analysis are reported in Table 4

Table 4. Amplification factor for the Cona area, computed from the local seismic response analysis.

codice	$FA_{0.1-0.5}$	$FA_{0.5-1.5}$	$FH_{0.1-0.5}$	$FH_{0.5-1.5}$
000046xa_038008	1.640	1.739	2.438	1.626
000126xa_038008	1.635	1.826	2.667	1.716
000354xa_038008	1.456	1.753	2.564	1.610
media	1.577	1.772	2.556	1.651

where:

$$FA_{0.1\text{-}0.5} = \frac{SI_{0.1\text{-}0.5}(PSVoutput)}{SI_{0.1\text{-}0.5}(PSVinput)}$$

$$\mathrm{FA}_{0.5\text{-}1.5} = \frac{\mathrm{SI}_{0.5\text{-}1.5}(\mathrm{PSVoutput})}{\mathrm{SI}_{0.5\text{-}1.5}(\mathrm{PSVinput})}$$

$$\mathrm{FH}_{0.1\text{-}0.5} = \frac{\mathrm{SI}_{0.1\text{-}0.5}(\mathrm{PSAoutput})}{\mathrm{SI}_{0.1\text{-}0.5}(\mathrm{PSAinput})}$$

$$\mathrm{FH}_{0.5\text{-}1.5} = \frac{\mathrm{SI}_{0.5\text{-}1.5}(\mathrm{PSAoutput})}{\mathrm{SI}_{0.5\text{-}1.5}(\mathrm{PSAinput})}$$

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