

Seismic modeling of San Donato area of the ancient mining area of Santa Barbara (Toscany – Italy)

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Abstract

As part of the environmental impact evaluation of the mining site, this research was conducted to set the rehabilitation plan by the *Commissione Tecnica di Verifica dell'Impatto Ambientale, Ministero per i Beni e le Attività Culturali and Regione Toscana*. This article presents the results of Local Seismic Response analysis carried out by geotechnical, geological, geomorphological, hydrogeological, and geophysical surveys in order to verify seismic stability conditions in San Donato waste disposal by classifying zones into stable, instable and susceptible to seismic amplification, in the lignite mine district of Santa Barbara located in the central part of Tuscany (Italy) and including a part of the depression of the valley, which extends about 40 km NW-SE, known as the Upper Valdarno. And to be used in environmental impact evaluation by theThe subsoil geotechnical model and its parameters are defined on the basis of a careful campaign of geotechnical and geophysical survey in the area of San Donato, supplemented by other surveys information available in the area of Santa Barbara. The area is characterized by shallow anthropogenic Holocene deposits. These deposits are deposited above fluvial - lacustrine ground of the Upper Valdarno formed by clay and sandy soil that are part of Montevarchi and Castelnuovo synthem with a pre-lacustrine substratum known as "Medium Oligocene – lower Miocene" Sandstone. The results of the Local Seismic Response analysis were compared with simplified approach of NTC (2008). According to the NTC (2008) the comparison indicates that the simplified procedure based on elastic spectrum response defined by the subsoil category (V_{S30}) tends to underestimate the seismic action and should be used with caution in the presence of Vs inversion with depth.

Keywords: San Donato, Shear wave velocity, Subsoil category, Local seismic response (RSL), Peak ground acceleration, seismic hazard, resonance frequency, amplification.

1. Introduction

There is no doubt that Italy is among the most seismic countries in Europe, enough to remember more than 120,000 victims in the last 100 years, more than 100 billion Euros of damage in the past 25 years and the fact that every few years the country is hit by a destructive earthquake. It is known that the earthquakes are not deterministic processes, which follow Gaussian statistics and therefore definable through arithmetic averages, but are Poisson processes, namely processes that represent the absolute randomness.

The Seismic Risk in Italy should therefore be dealt with in an extremely serious way. And it is, but only in part. Let's see why. Let's recall the Seismic Equation Risk = Hazard x Vulnerability x Exposed Value, where the hazard is the probability that each site has to be the epicenter of an earthquake of a given magnitude in a certain interval of time, the Exposed value is the value of a set of people and things present in the area and Vulnerability indicates the lack of structures resistance to earthquake forces.

The case study of San Donato village is the result of an interdisciplinary work which includes the evaluation of seismic hazard that depends on regional seismogenic structures, geomorphological and geological characteristics (superficial and deep), as well as geophysical and geotechnical ones of the crossed soils. .

This study has as purpose to evaluate the effects of site and more accurately define the local seismic response of San Donato site in comparison with the simplified procedure allowed with some restrictions from NTC 08.

The current regulations in Italy (DM 14/01/2008, Norme Tecniche per le Costruzioni) derive from the European legislation (Eurocode 7 and 8). It follows, since an earthquake of reference is provided by the relevant authorities for each municipality, these steps:

- ✓ soil classification from a seismic point of view (using VS30, NSPT, undrained cohesion Cu or similar);
- ✓ site effects estimation (amplification and the ground seismic specter response);
- ✓ the earthquake impact evaluation on the mechanical behavior of the soil;
- ✓ any subjective evaluation of topographic effect.

The purpose of this legislation is the development of soil's classification in order to estimate the elastic spectrum response for the horizontal component of motion and in particular the main resonance frequency of the subsoil. It's the key parameter for engineers who must absolutely avoid double resonance which is the real cause of destruction by earthquake.

In S.Donato site, many site effects phenomena are present, but especially soils landslides and liquefaction, both described effectively by geomorphological and geotechnical engineering investigation methods. Besides those two site effects we can describe others that are presented in San Donato site (Figure 1) like sand boils, great oscillations and ground ruptures, lowering and lifting of the ground, lateral spreading of the ground, masses fluid movement, natural and artificial slopes collapse, bearing capacity loss of the foundations, floating of underground artworks and collapse of artworks support.

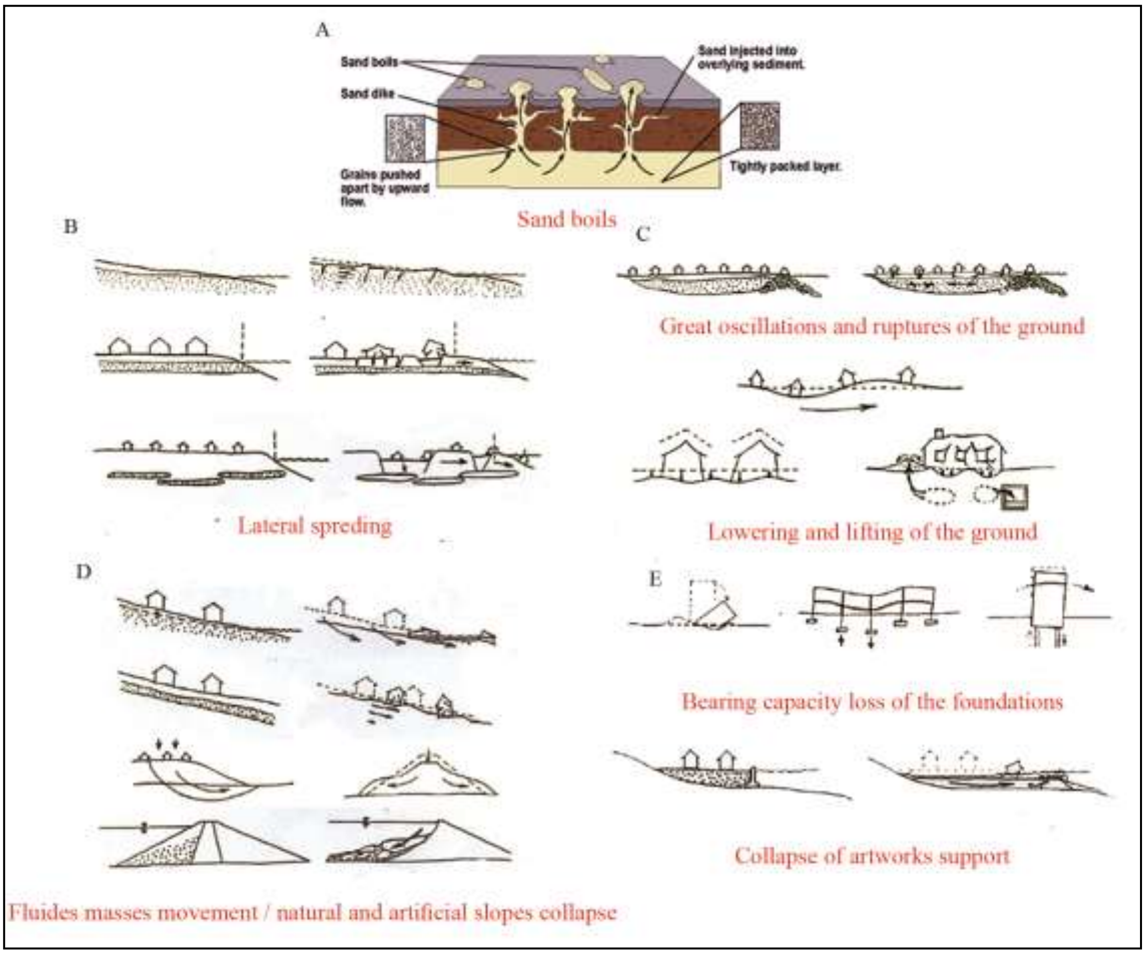

Figure 1. Sand boils (A), Schemes of cyclic mobility manifestations (B, C), Schemes of fluidization manifestations (D, E). (Dipense corso geoingegneria, Eros Aiello 2014)

The influence of the morphology of the surface and the underground on the seismic response has been widely highlighted in numerous theoretical studies and documented by the observation of several real cases. However, even the most recent studies of micro-zoning based on numerical models, have been frequently used to predict the site effects especially one-dimensional models, but neglected the effects of the real subsurface geometry. In order to contribute to this discussion, they were made in comparison to results of series of local seismic response analysis carried out at the site of San Donato, using one-dimensional (1D) numerical models.

The 1D analysis were performed with the code Strata one-dimensional which models a soil column as a continuous stratified with a linear visco-elastic behavior. The equations of motion are solved in the frequency domain through the calculation and the subsequent convolution of the transfer functions of each layer. The non-linearity of the dynamic properties, independent from frequency, is assumed using the equivalent linear approach.

In order to define in detail the model of the underground for local seismic response analysis, geological and geotechnical investigations were carried out for microzonation studies.

2. Geological and geomorphological framework

The blue frames in Figure 2 illustrate the area of San Donato in which specific surveys (geological, geomorphological, geophysical and geotechnical) were carried out to verify its stability conditions.

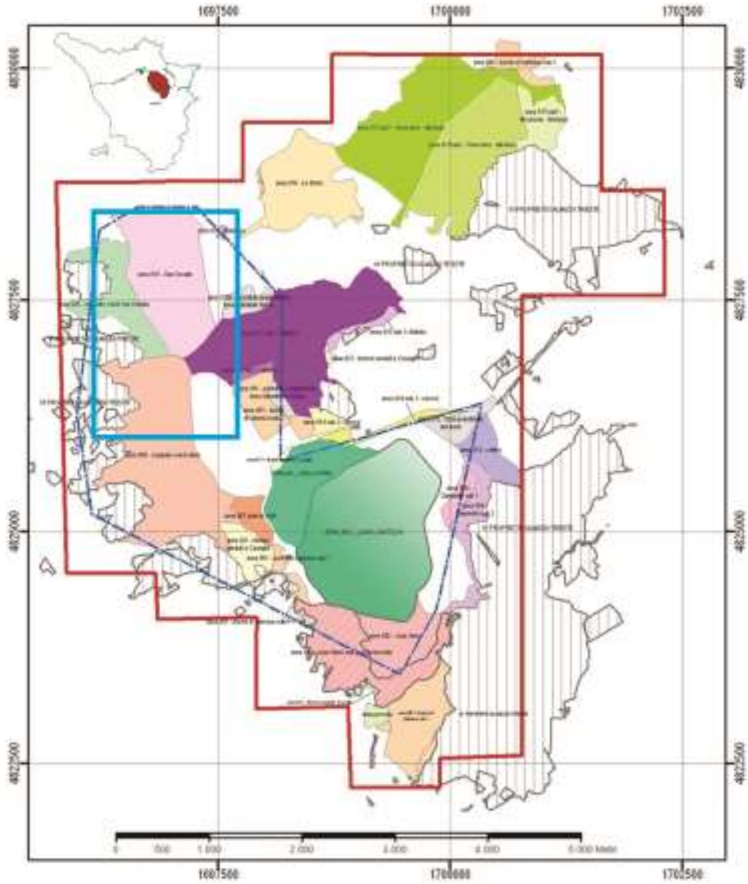

Figure 2. Location map of the area of study (framed in blue).

For the purpose of this work, we focused particularly on the phases that characterized the sedimentary basin's fillings to understand how we got the current structure (Figure 3). There were three major phases of deposition; each one corresponds to a tectonic phase of activation and reactivation of normal faults. They are separated by clear boundaries represented by angular discordance and erosion surfaces extending on the entire basin.

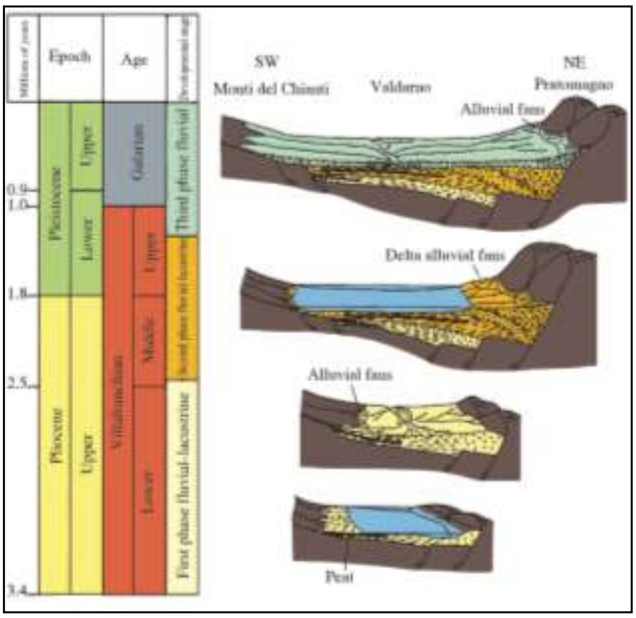

Figure 3. Schematic paleogeographic evolution of Upper Valdarno's fluvial - lacustrine basins (Sagri, and al., 1993).

The first stage began with the appearance of a marshy - lake middle, ideal for the implementation of a bog and this has led to a significant accumulation of organic matter and the formation of clay deposits. The deepening depression and simultaneous uprising of water level controlled the disappearance of the peat formed on the margins of the basin. Under these conditions, 200 meters of sediment composed of clay (Meleto clays) alternating with silty deposits were accumulated. This phase ended with the deposition of San Donato sands accumulated through alluvial fans of the Chianti Mountains. The deposits belonging to this phase of sedimentary structures are from Castelnuovo Group.

At the end of the lower Villafranchian, the deposits of this group were affected by tectonic movements that affected the basin, especially in the north - west where the reactivation of major faults at the base of Pratomagno dorsal significantly contributed to the growth of the size of the Upper Valdarno Basin.

During the second phase of deposition, after deformation and inclination toward the NE of Castelnuovo's sediments, a fairly large and deep lake was created in the upper Valdarno , where sediments of Montevarchi Group are deposited. These later sediments consist mainly on Marshy - lake deposits in the central part and also on delta - alluvial fan sediment in marginal areas. The marshy - lake deposits include, from bottom to top, Terranova silts, clays of Torrente Ascione sands and silts of Torrente Oreno which are frequently presented by reddish levels and paleosols, that characterize periods of partial desiccation on the Lake.

Vertical tectonic movements and the important contributions of clastic material in the depression of Valdarno basin allowed determining at the end of the Pleistocene the extinction of the lake and the beginning of the third stage of deposition (Middle Pleistocene). The drastic change in the drainage area of Valdarno had a great impact on the deposits, the waters of the paleo-arno, which in preference flew in Val di Chiana, in the Middle Pleistocene began to flow into the lower parts of the basin with a sinuous path and the deposition of gravel, sand and silt. This phase corresponds to the deposition of Monticello Group sediments in the part of paleo-arno and the deposition of Ciuffenna alluvial fan sediments in the margins of the basin at the foot of the Chianti Mountains as well as Pratomagno dorsales. These deposits rely on the second sequence with a slight angular unconformity marked by a paleosol while in the central part theses deposits are separated by an erosional surface.

Figure 4 shows the stratigraphic log of Valdarno.

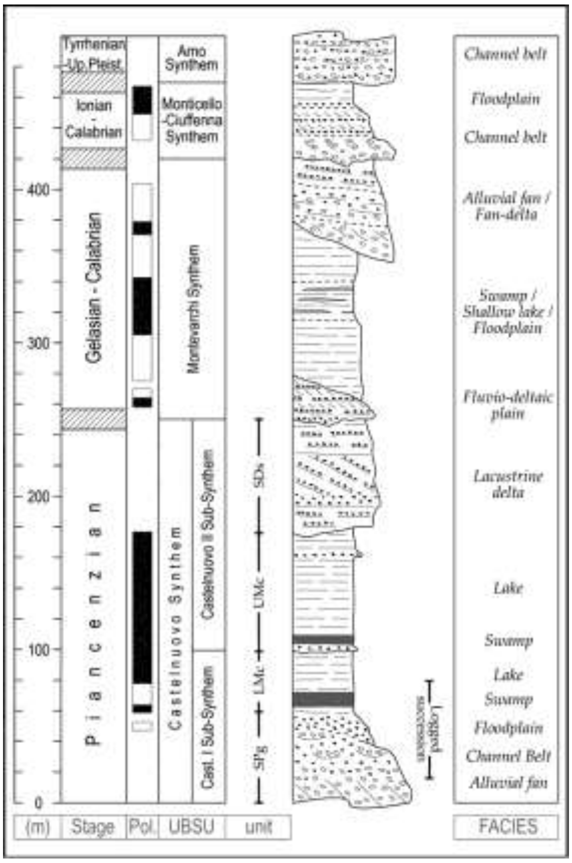

Figure 4. Stratigraphic log of Valdarno (Ielpi, 2011). SPg: Conglomerates and sands of Spedalino LMc, UMc: Meleto clays , SDs: Sands of S. Donato.

The area of San Donato was mined until 1994, the year of maximum depth (about 100 m above sea level at the deepest point), after which the partial filling was carried out, up to an altitude of approximately 175-180 m above sea level. The slope of the anthropic excavation is set along the eastern side of the Chianti Mountains, at the contact between the Oligocene formations of the Apennines orogeny and the Plio-Pleistocene deposits of Neogene basin of the Upper Valdarno (Figure 5).

In the area of study the outcroping sandstone of Macigno and gray shales with limestones known as Scagliose Clays have the same inclination as the olistostrome intercalated within the sandstones above. From a geological point of view the sector is highly complex due to the difficulty to adequately interpret the particular structural-tectonic formations based on their altered relationships resulted from intense and profound changes caused by mining on the site.

The Scagliose clay, outcropping immediately in the upstream of the main detachment niches and embankments of landslide in the area of San Donato, is composed by an heterogeneous complex without any sedimentary order within which a complete chaotic portion is recognized, like in the area of Vignale and in the area of the quarry not far from Borro dela Lupa where portions of intercalating sedimentary sequences are encountered.

The sandstones often show cataclastic zones and discontinuity surfaces affected by kinematic indicators slickensides which attribute the entire complex to a fault rock with more or less preserved multi metric blocks.

With regard to fluvial-lacustrine deposits, the Castelnuovo sequence begins with clastic terms from coarse (conglomerates and Spedalino sands) to sandy (basal facies of Meleto Clays) to then move gradually to sandy pelitic and finally to clay terms. The Spedalino conglomerates are found in a wide area around Castel dei Rossi, where the apical zone of the alluvial fan can be located. Close by this location, the conglomerates show a very proximal character, where metric sandstone blocks are totally rounded and without any internal organization. Downstream, these deposits are gradually less coarse, going from a prevalence of decimeter fragment, to centimeter, then to a progressive increase in sorting. In the distal parts of the alluvial fan the fragment has fluvial characters.

Based on the landslides distribution map derived from the IFFI (Inventario Fenomeni Franosi italiani) database at 1: 15 000 scale (Figure 6) it is clear how the area is affected by active landslide (yellow) and superficial and/or distributed movements (in green).

Currently the site of San Donato is very irregular. In the morphological point of view large areas are not viable, with steep slopes, neoformation morphemes, stagnant water and the evidence of incipient movements.

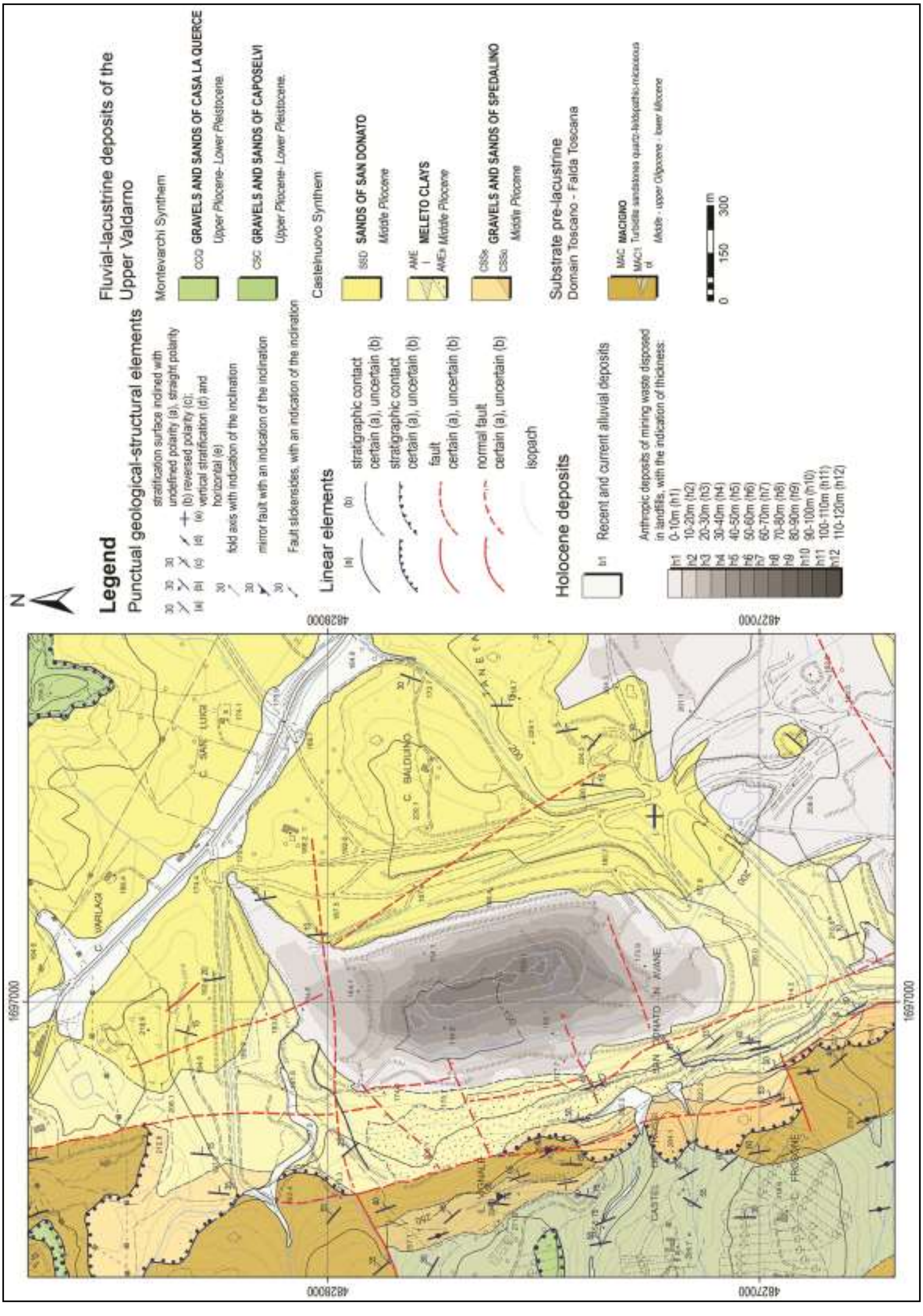

Figure 5. Geological map of San Donato.

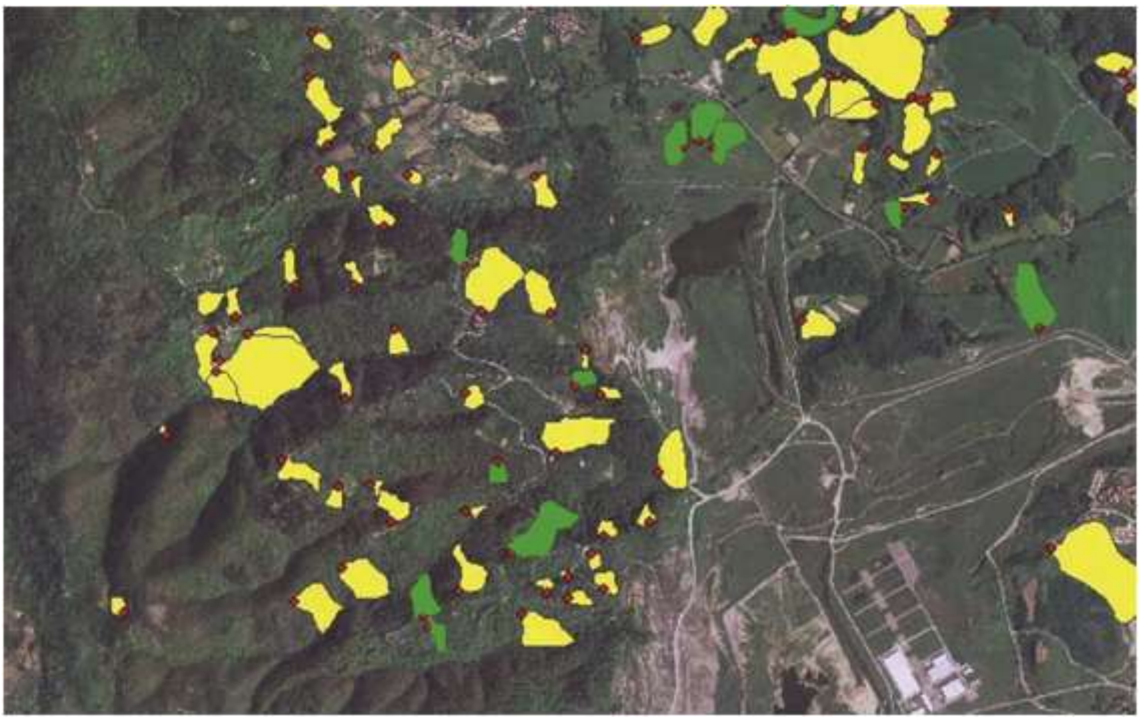

Figure 6. Distribution of active landslides (yellow) and superficial and / or distributed movements (green) (Extracted map from the IFFI).

3. San Donato underground model

The model of San Donato's underground has been reconstructed based on the geological information and results of a large number of geophysical and geotechnical investigations carried out in the Santa Barbara area between 2011 and 2012 and in particular:

- ✓ 5 continuous probing geo-gnostic, at varying depths;
- ✓ execution of five S.P.T. (standard penetration test) tests to verify the mechanical resistance of the field and 2 C.P.T. (cone penetration test) tests;
- ✓ execution of a seismic profile M.A.S.W. (Multichannel Analysis of Surface Waves) and one seismic refraction profile of S waves in order to reconstruct the trend of the underground sismo-stratigraphy and to get the velocity of S waves in the first 30 meters depth (V_{S30});
- ✓ 6 H.V.S.R. (Horizontal-to-Vertical Spectral Ratio) measurements (ambient seismic noise) ;
- ✓ 1 geo-electrical tomography to better define the underground stratigraphy through the electro-layers.

Those investigations are represented in Figure 7.

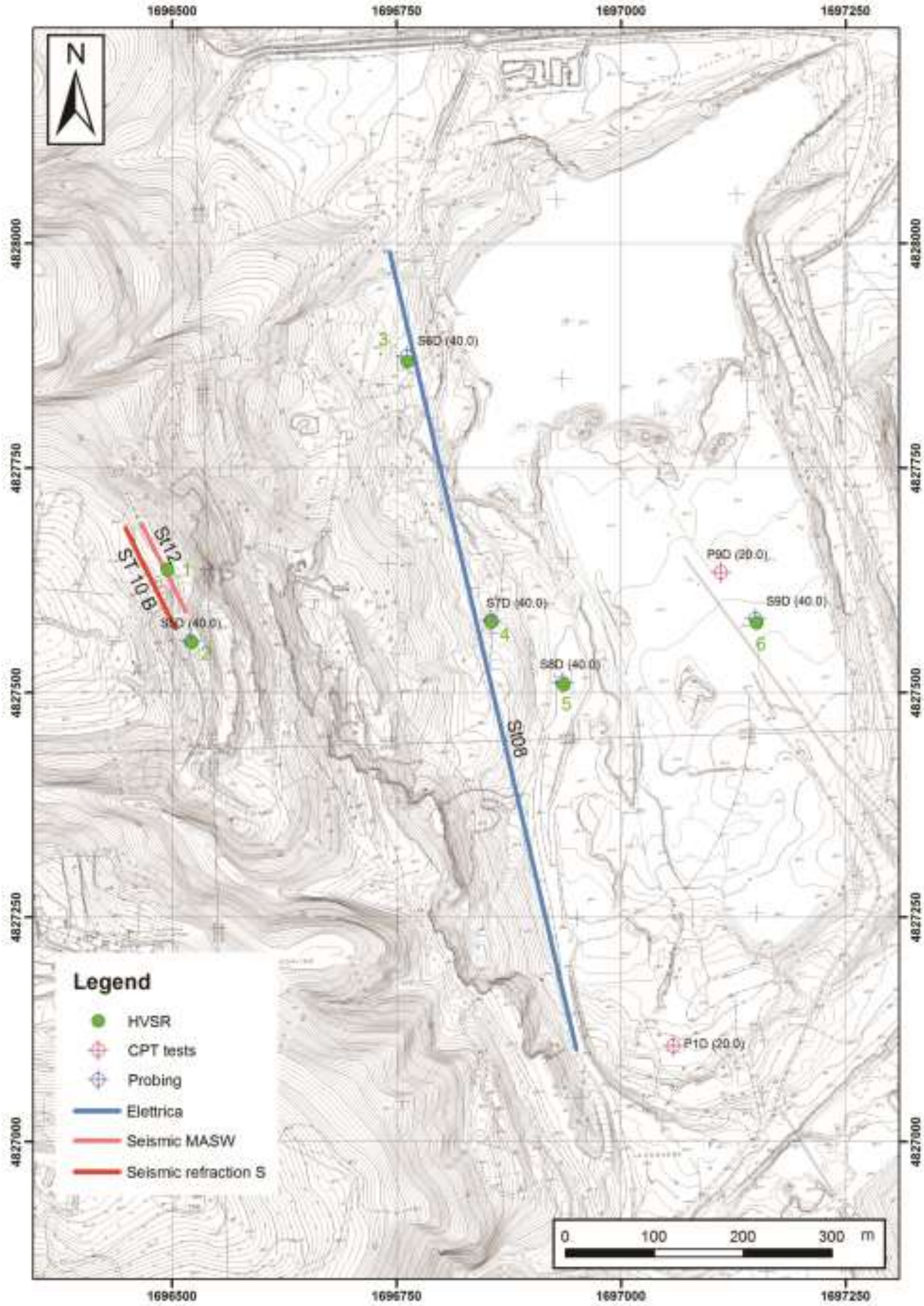

Figure 7. Status of existing surveys and new geophysical surveys in the area of San Donato.

Having access to the results of penetration tests, such as CPT values of qc resistance, it is possible to obtain a direct estimate of V_S value using empirical relationships from literature.

Calculating V_{S30} obtained on the basis of Vs values (1) for both tests P1D and P9D (Figure 8, Figure 9) in the area of San Donato, estimated by empirical correlations, provides a V_S values that list the site within the category of Type C subsoil (Table 1).

$$Vs_{30} = \frac{30}{\sum_{i=1,N} \frac{h_i}{V_i}} \quad (1)$$

$$N_{SPT,30} = \frac{\sum_{i=l,M} h_i}{\sum_{i=l,M} \frac{h_i}{N_{SPT,i}}}$$

Where

- hi and Vi respectively indicate the thickness in meters and the velocity of shear waves in the i-th layer, for a total of N layers present in the first 30 meters depth;
- N_{SPT},i shot number N_{SPT} at the i-th layer;
- N number of layers present in the first 30 m depth;
- M number of coarse-grained soils layers present in the first 30 m depth;
- K number of fine-grained soils layers present in the first 30 m depth.

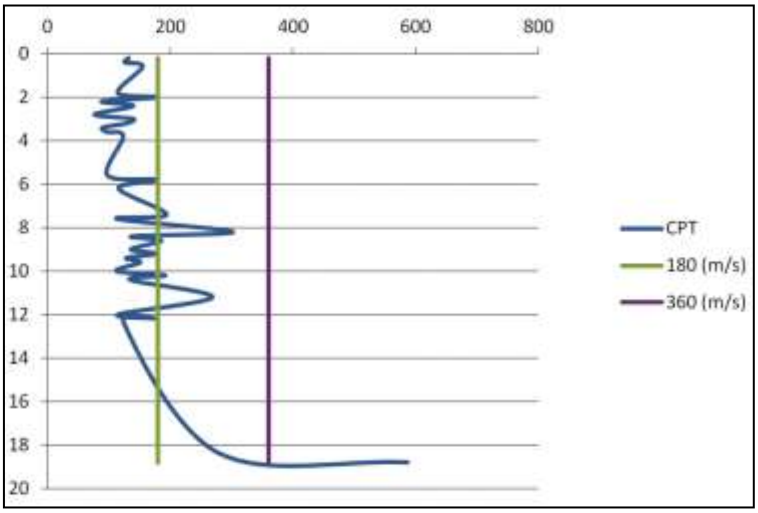

Figure 8. Vs values estimated by empirical correlations from the results of CPT tests of P1D.

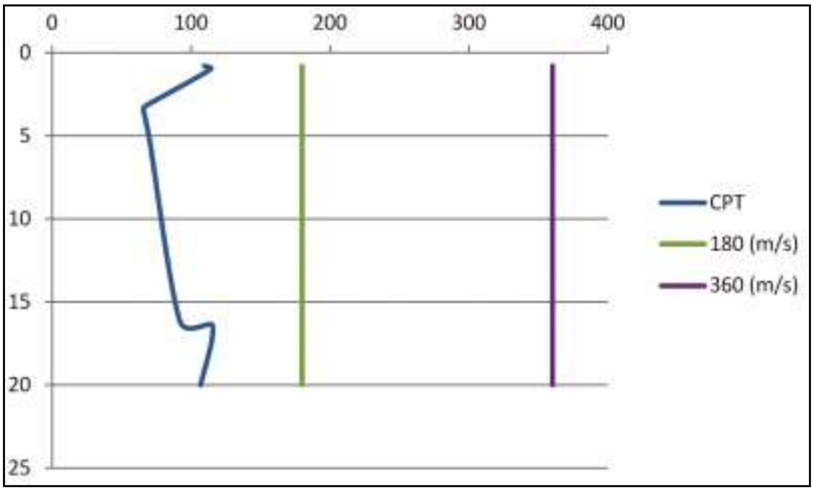

Figure 9. Vs values estimated by empirical correlations from the results of CPT tests of P9D.

Category	Description
A	Outcropping rocks or a very hard soil characterized by Vs_{30} values, greater than 800 m/s, that include an altered surface layer, with a thickness of 3m.
B	Pout rocks and very consistent deposits of dens or fine grained soils with thickness greater than 30m, characterized by a gradual improvement of mechanical properties in depth and $Vs_{,30}$ values ranging from 360m/s to 800 m/s (or $N_{SPT,30}$ >50 in coarse-grained soils and $C_{u,30}$>250kPa in fine-grained soils).
C	Consistent deposits of moderately dens coarse or fine grained soils with thickness greater than 30 m, characterized by a gradual improvement of mechanical properties in depth and $Vs_{,30}$ values ranging from 180m/s to 360m/s (or 15< $N_{SPT,30}$ < 50 in coarse-grained soils and 70<$C_{u,30}$<250kPa in fine-grained soils).
D	Less consistent deposits of coarse and less dens or fine grained soils thicker than 30m, and characterized by a gradual improvement of mechanical properties in depth and $Vs_{,30}$ values less than 180 m/s (or $N_{SPT,30}$ <15 in coarse-grained soils and $C_{u,30}$ <70kPa in fine-grained soils).
E	C or D subsoil type less thicker than 20m and situated in the reference substratum (with Vs> 800 m/s)

Table 1. Subsoil categories classification according to NTC08, D.M. 14/01/2008.

N_{SPT} and N_{SPT30} (1) values helped to obtain velocity profiles of shear waves propagation presented in Table 2. The values of Vs were estimated from N_{SPT} values using the empirical relationship of Ohta and Goto (1978):

$$V_s = 68.79\, N_{SPT}^{\ 0.171}\, H^{0.199} f_A f_G \qquad (2)$$

Where

- N_{SPT} is the number of hits obtained from the SPT test,
- H is the depth in meters from ground level,
- f_A *and* f_G are two factors that take into account, respectively, the geology and soil type at the time of deposition

Probing	Prof. (m)	N_{SPT} (Hits / feet)	Volume weight (KN/m^3)	Density (KN/m^3)	V_S (m/s)	$N_{SPT,30}$	Underground category
S5D	5	45	20.4	2.08	238.93	76	B
	10	54	20.3	2.07	283.06		
	15	61	20.8	2.12	313.39		
	25	94	20.7	2.11	373.87		
	35	94	19.8	2.02	399.76		
S7D	5.5	22	19.5	1.99	215.15	60	B
	15.5	56	20.8	2.12	310.81		
	25.5	70	20.8	2.12	356.68		
	35.5	73	20.2	2.06	383.73		
S8D	5.5	9	16.4	1.67	184.33	11	D
	15.5	11	16.5	1.68	234.54		
	35.5	13	17.7	1.8	284.7		
S9D	35.5	35	18.8	1.92	337.91	10	D

Table 2. Evaluation of underground's soils in San Donato.

The appropriate H / V curves (Figure 10) allowed to highlight two peaks, the first with a frequency of 9:03 Hz, the second between 1:13 and 3:09. It's possible to associate the peak with the highest resonant frequency to the contact between the substrate and the overlying altered sandstone and sandy clay deposits. This contact is characterized by a depth which may vary from 5 to 15 m; the second peak is explained by the significant impedance contrast that is probably related to the transition between the altered sandstone substrate and the compact one, found in a depth interval between 50 to 100 m.
The H / V curve of the San Donato has allowed us to reconstruct the approximate profile of Vs up to 100 m depth corresponding to the last reflector identified by the peak at 1:13.
In tomography ST 08 (Figure 11) we note the presence of a first electro-layer with variable resistivity between 5 and 30 Ωm and increasing thickness from north to south for about ten to several tens of meters; on the basis of information derived from the probing listed in the tomography, we can assume that this electro-layer is related to clay deposits mixed with lignite and sandy-clayey deposits.
The second electro-layer, characterized by a range of resistivity between 30 and 50 Ωm, is detected only in the central part of the profile. It tends to deepen towards the south and is attributable to clayey sands cemented by fragment of sandstone. This later is interpreted as the most superficial part of the sandstone associated to the third electro-layer which is only visible in the northern part of the profile, with a resistivity from 50 to 120 Ωm.
With the continuous probing surveys carried in the area and using the various techniques of investigation (CPT, SPT, laboratory tests, geology, geotechnical test, geophysics surveys) was processed the geological and geotechnical model for site of interest (Figure 12).

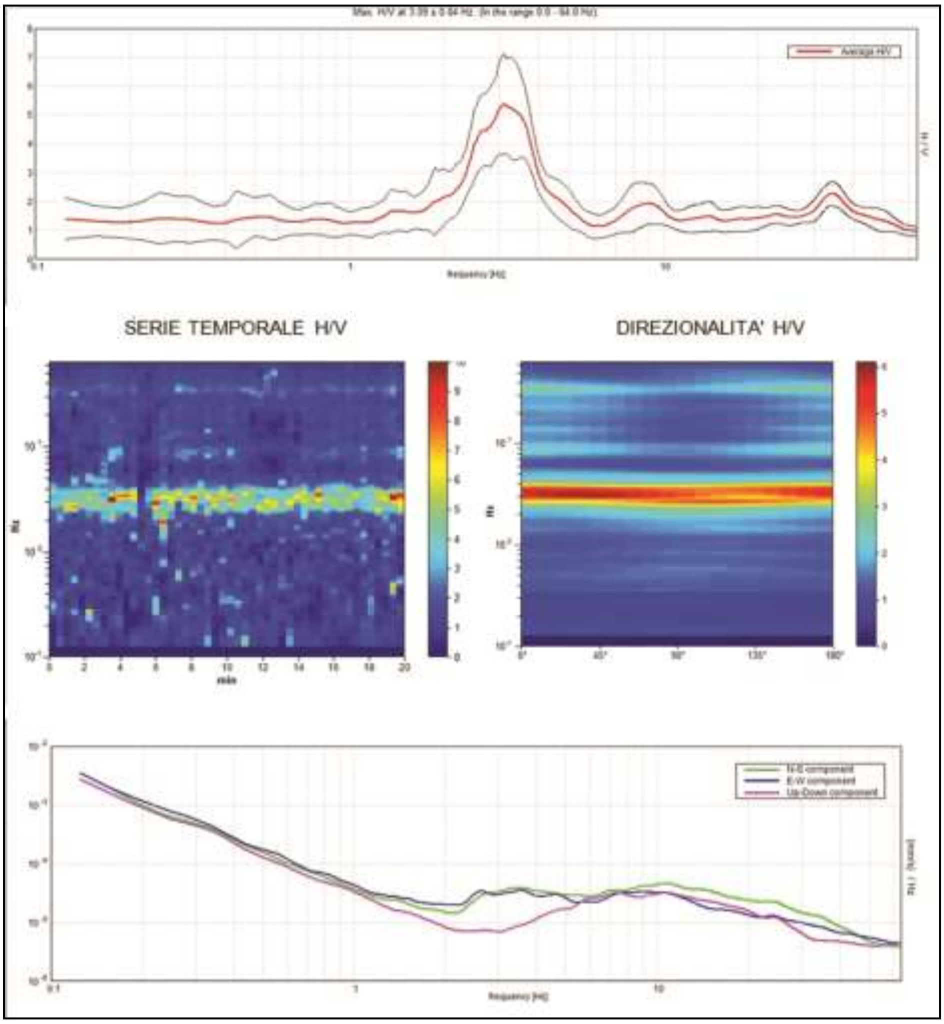

Figure 10. H / V experimental spectral ratio and individual components of the HVSR 3 spectra.

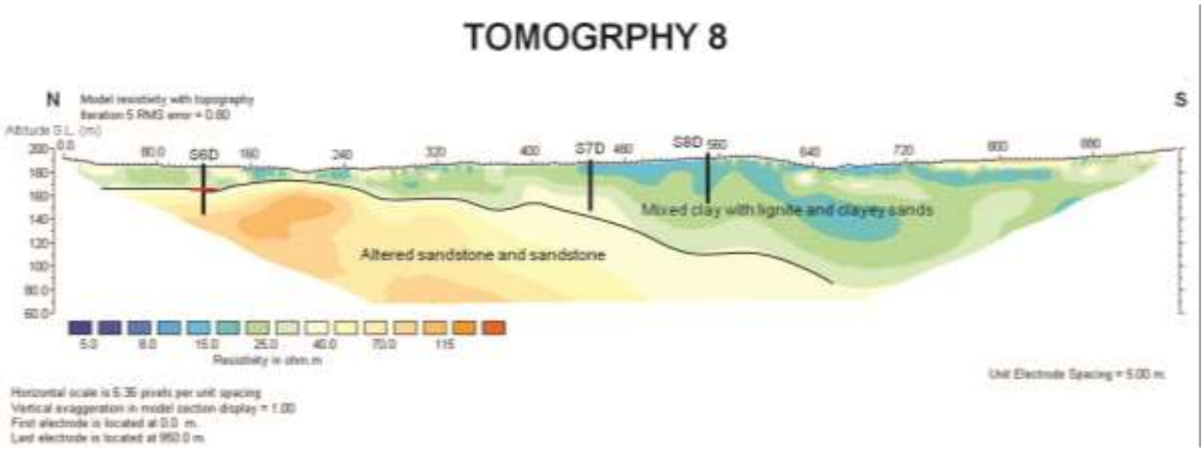

Figure 11. Electric tomography ST-08.

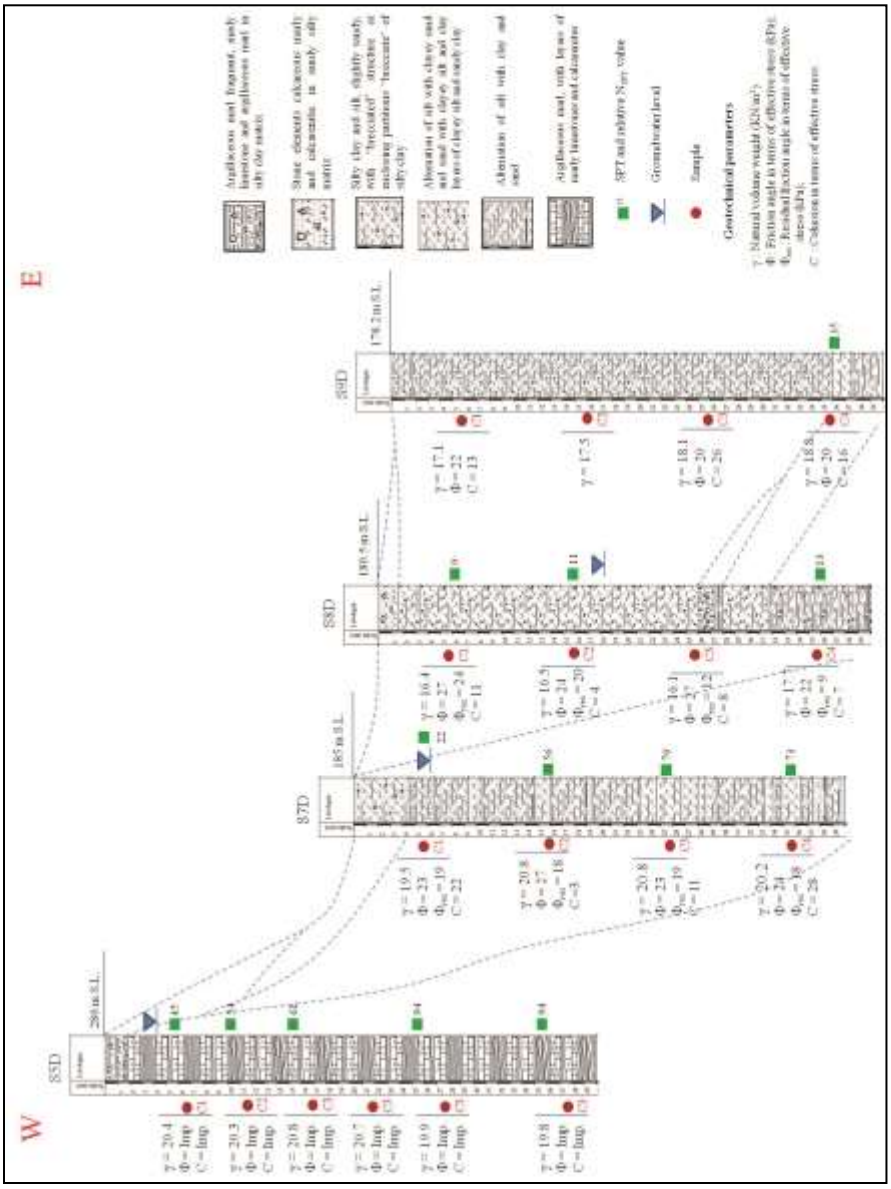

Figure 12. Geological model and geotechnical parameter values of San Donato.

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4. Analysis of local seismic response in San Donato site

4.1 Estimation of the base acceleration

For the site of interest, with defined geographic coordinates, the planning choices (Rated Life VN coefficient of Use Cu are respectively equal to 50 years and 1.0 with Reference Period VR = 50 years) and the range of magnitude M and distance R are most likely based on the analyzes of disaggregation provided by the INGV Project S1 (http://esse1-gis.mi.ingv.it/), 10 seismic-compatible combinations were obtained using the response spectrum of the site. Among which the combination with the minor average deviation was chosen, where seven accelerograms, scaled appropriately based on the maximal estimated acceleration (for the state limit of Life Safety and for State Limit of Damage), are natural and present in the "European Strong-motion Database" (ESD).

The base acceleration was estimated through the program "Parametri Sismici" (Geostru) and verified by the Spettri – NTC ver. 1.0.3 spreadsheet of CSLP.

To determine the site's hazard parameters, we used 4 grid elementary points in the mesh containing the point to examine. The coordinates of these sites and the distance values from the point of measurements are listed below:

- ✓ HVSR 3

Site 1	ID: 20949	Lat: 43,5665	Lon: 11,4201	Distance: 1914,795
Site 2	ID: 20950	Lat: 43,5678	Lon: 11,4890	Distance: 4314,145
Site 3	ID: 20728	Lat: 43,6177	Lon: 11,4874	Distance: 5950,143
Site 4	ID: 20727	Lat: 43,6165	Lon: 11,4184	Distance: 4523,014

- ✓ HVSR 4

Site 1	ID: 20949	Lat: 43,5665	Lon: 11,4201	Distance: 1821,350
Site 2	ID: 20950	Lat: 43,5678	Lon: 11,4890	Distance: 4256,212
Site 3	ID: 20728	Lat: 43,6177	Lon: 11,4874	Distance: 6059,641
Site 4	ID: 20727	Lat: 43,6165	Lon: 11,4184	Distance: 4681,933

For the site of San Donato, the results of the basic acceleration and the characteristics of each site are listed below.

The HVSR 3 measurement classified the sites under C category type subsoil and T1 category type topography (Table 1, Table 3). The basic seismic hazard, considering a reference period of VR = 50 years, is defined by the maximum acceleration to the site and the attached parameters to the elastic response spectrum (Table 4). The seismic coefficients are listed in Table 5.

Category	Description
T1	Flat surface, slopes and isolated reliefs with an average inclination ≤ 15 °
T2	Slopes with an average inclination > 15 °.
T3	Reliefs, wide in the base than in the crest with an average inclination 15°≤ i ≤ 30°.
T4	Reliefs, wide in the base than in the crest with an average inclination i >30 °.

Table 3. Topographic category (NTC08, D.M. 14/01/2008)

	Exceedance probability	T_R(years)	ag (g)	Fo	Tc* (s)
State Operational Limit (SLO)	81%	30	0,044	2,587	0,255
State Dammage Limit (SLD)	63%	50	0,052	2,613	0,267
State Life Safety Limit (SLV)	10 %	475	0,123	2,393	0,299
State Collapse Prevention Limit (SLC)	5 %	975	0,157	2,406	0,302

Table 4. Seismic hazard parameters for 50 years return periods in San Donato HVSR 3 Site.

	Ss	Cc	St	kh	kv	a_{max}	Beta
SLO	1,500	1,650	1,000	0,013	0,007	0,643	0,200
SLD	1,500	1,620	1,000	0,016	0,008	0,772	0,200
SLV	1,500	1,560	1,000	0,044	0,022	1,816	0,240
SLC	1,470	1,560	1,000	0,055	0,028	2,262	0,240

Table 5. Seismic coefficient of San Donato HVSR 3 Site.

Where

- kh et kv respectively equal to the horizontal and vertical kinematic seismic coefficients;
- a_{max} maximal acceleration ;
- S_S stratigraphic amplification coefficient ;
- S_T topographic amplification coefficient ;
- T_C is the period corresponding to the start of the spectrum at a constant speed, given by $T_C=C_C. T_C*$
  - where T_C* is defined according to the area and C_C is a coefficient depending on the category of the subsoil;
- Fo amplification factor of the spectrum in horizontal acceleration;
- ag maximum horizontal acceleration ;
- TR return period.

The HVSR 4 measurement classified the sites under B category type subsoil and T1 category type topography (Table 1, Table 3). The seismic hazard parameters for the return periods required by NTC08 are listed in Table 6 and the seismic coefficients in Table 7.

	Exceedance probability	T_R(years)	ag (g)	Fo	Tc* (s)
State Operational Limit (SLO)	81%	30	0,044	2,588	0,255
State Dammage Limit (SLD)	63 %	50	0,052	2,613	0,267
State Life Safety Limit (SLV)	10 %	475	0,123	2,393	0,299
State Collapse Prevention Limit (SLC)	5 %	975	0,157	2,406	0,301

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State Collapse Preventtion Limit (SLC)	5 %	975	0,157	2,406	0,301

Table 7. Seismic coefficient of San Donato HVSR 4 Site.

4.2 Seismic hazard disaggregation data

The probabilistic seismic hazard analysis results above provide the accelerations corresponding to a predetermined return period, but they do not contain any information about the earthquake MAGNITUDE M that may have generated it, or about the DISTANCE R (km) from the source. These characteristics can be obtained by the disaggregation process.

The seismic hazard disaggregation (McGuire, 1995; Bazzurro and Cornell, 1999) is a procedure by which the earthquake parameters that most influence the site's seismic hazard are determined. The disaggregation is an operation that allows evaluating the relative contribution of seismic hazard different sources in the site. The most common form of disaggregation is the two-dimensional MAGNITUDE (M) of the site and DISTANCE from the earthquake source (R) it defines the contribution of seismogenic sources at R DISTANCE capable of generating earthquakes of magnitude M.

In practice, assuming that the acceleration exceeds a certain value of interest, the disaggregation is calculated for each possible pair M and R, the probability of that excess is due to those pairs.

The national seismic hazard data was provided by INGV (Istituto Nazionale di Geofisica e vulcanologia).

4.3 Extraction of the ground motion input (accelerograms)

The Rexel v. 3.3 beta software (Iervolino et al, 2008-2011) was used to extract the motion input. This software allows searching for combinations of compatible natural accelerograms with the Technical Standards spectra to be used in Construction purpose (Norme Tecniche per le Costruzioni NTC 2008 - D.M.14.01.2008) and Eurocode 8 (EC8). These combinations may also reflect the source of interest characteristics in terms of magnitude M and epicentral distance R. In general, it is more appropriate to use natural accelerograms, as more realistic, as required for work and NTC 2008 geotechnical systems then to use artificial accelerograms in order to get the local seismic response analysis and to deal with geotechnical problems.

The accelerometer recordings referred to in REXEL are those of the European Strong-motion Database (ESD). The program automatically defines, for any place in the country, the spectra of horizontal and vertical components starting with the geographic coordinates, the local geology, the state limit under consideration, the nominal life and the classes of use. Once the reference is defined, it's possible to select real accelerograms belonging to a particularly chosen MAGNITUDE M and R DISTANCE intervals. Those accelerograms will be then used to create combinations of seven entries, for the previously defined spectrum, with an upper and lower tolerance suitably selected. REXEL returns a file that summarizes the characteristics of selected records and the earthquake identification codes associated to each set of accelerograms found. In fact, every earthquake can have multiple acceleration records obtained by placing the measuring instruments (accelerometers) in several places. Several accelerograms can then submit the same code for the same earthquake of origin.

The sets are obtained automatically sorted by ascending order of dispersion with respect to target spectrum characterized by the following deviation parameters (Iervolino and al., 2008), spectral deviation (δj), spectral deviation average ($\delta medio$) and maximal spectral deviation (δmax):

$$\delta_j = \sqrt{\frac{1}{N}\sum_{i=i}^{N}\left(\frac{Sa_j(T_i) - Sa_{t\arg\ et}(T_i)}{Sa_{t\arg\ et}(T_i)}\right)^2}$$

$$\delta_j = \sqrt{\frac{1}{N}\sum_{i=i}^{N}\left(\frac{Sa_{medio}(T_i) - Sa_{t\,arg\ \,et}(T_i)}{Sa_{t\,arg\ \,et}(T_i)}\right)^2}$$

(3)

$$\delta_j = \frac{max}{inaset}\sqrt{\frac{1}{N}\sum_{i=i}^{N}\left(\frac{Sa_j(T_i) - Sa_{t\,arg\ \,et}(T_i)}{Sa_{t\,arg\ \,et}(T_i)}\right)^2}$$

Where

- Sa_j (Ti) is the pseudo-acceleration spectral ordinate of the i-th accelerogram at the period Ti;
- Sa_{target} (Ti) is the pseudo-acceleration spectral ordinate of the target spectrum in correspondence to the period Ti;
- Sa_{medio}(Ti) is the pseudo-acceleration spectral ordinate average of the real set of accelerograms in correspondence to the period Ti;
- N is the number of points observed within a specified range of periods;

The spectral deviation average (*δmedio*) provides a quantitative measure of the deviation. It assumes the trend of the average spectrum relative to the single combination connected to the examined spectrum reference.

The maximum deviation (*δmax*) of the single spectrum is the relative average deviation of each recording being part of the combination. According to this parameter, the selection provides the δmax in seven fold accelerograms and the characterized combinations by the minimum value assumed by it. This rule allows identifying the combinations in which the real spectra are less dispersed compared to the reference spectrum for example if you have to present more than one combination having the same minimum value of δmax deviation, the choice of the most appropriate can be obtained by considering the minimum value of *δ* deviation.

In addition, the program allows selecting scaled combinations of accelerograms for which average spectrum is compatible with the reference spectrum. Each accelerogram is first dimensioned to its peak ground acceleration (*PGA*) value and then linearly scaled by a factor so that the record *PGA* matches the standard spectrum *PGA*.

REXEL generates, if exists, the combinations of scaled records with average compatible-spectrum as long as the sizing operation is carried out and maximum average factor with a desired scale (SF) specified.

4.3.1 Converting and normalizing the input

After extracting a set of 7 earthquake accelerograms to be used as input it may be necessary before starting the evaluation of the seismic response to intervene on the extracted accelerograms to convert them into the format known by the RSL analysis software.

At the site of San Donato HVSR 3, we obtained the graph shown in Figure 13 where the different colors present the contribution percentage to the hazardous magnitude-distance corresponding to each square. These results are also shown in a table form below the graph, while in the other graphs (Figure 14) the mean values of Magnitude and Distance are shown and it appears that, in the case of S. Donato HVSR3 M= 4.0 ÷6.5 and R = 0 ÷30.

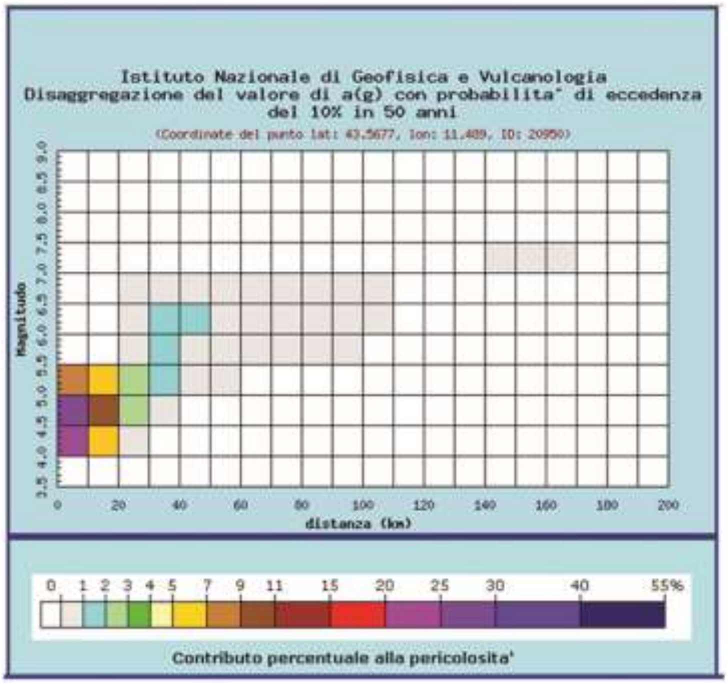

Figure 13. Age value disaggregation with 10% probability of exceedance in 50 years in S. Donato.

Distanza in km	Disaggregazione del valore di a(g) con probabilita' di eccedenza del 10% in 50 anni (Coordinate del punto lat: 43.5677, lon: 11.489, ID: 20950)										
	Magnitudo										
	3.5-4.0	4.0-4.5	4.5-5.0	5.0-5.5	5.5-6.0	6.0-6.5	6.5-7.0	7.0-7.5	7.5-8.0	8.0-8.5	8.5-9.0
0-10	0.000	24.200	29.400	8.740	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10-20	0.000	6.020	10.900	5.490	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20-30	0.000	0.335	2.200	2.630	0.887	0.500	0.079	0.000	0.000	0.000	0.000
30-40	0.000	0.000	0.173	1.470	1.620	1.340	0.233	0.000	0.000	0.000	0.000
40-50	0.000	0.000	0.000	0.209	0.908	1.030	0.157	0.000	0.000	0.000	0.000
50-60	0.000	0.000	0.000	0.024	0.408	0.495	0.042	0.000	0.000	0.000	0.000
60-70	0.000	0.000	0.000	0.000	0.092	0.255	0.018	0.000	0.000	0.000	0.000
70-80	0.000	0.000	0.000	0.000	0.008	0.113	0.008	0.000	0.000	0.000	0.000
80-90	0.000	0.000	0.000	0.000	0.000	0.041	0.003	0.000	0.000	0.000	0.000
90-100	0.000	0.000	0.000	0.000	0.000	0.009	0.001	0.000	0.000	0.000	0.000
100-110	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
110-120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
120-130	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
130-140	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
140-150	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000
150-160	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000
160-170	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
170-180	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
180-190	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
190-200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Valori medi		
Magnitudo	Distanza	Epsilon
4.820	11.600	1.000

Figure 14. Magnitude and distance average values of S. Donato for a return period of 50 years.

4.3.2 Extraction of accelerograms input

The horizontal component provided by NTC08 and the Compatibility between the average spectrum obtained for 7 natural accelerometers selected in the site of San Donato HVSR3 and the target spectrum (taken as reference) are shown in Figure 15. Looking at it, individual accelerograms give different contributions at different spectral periods and their average spectrum is presented in blue thick line.

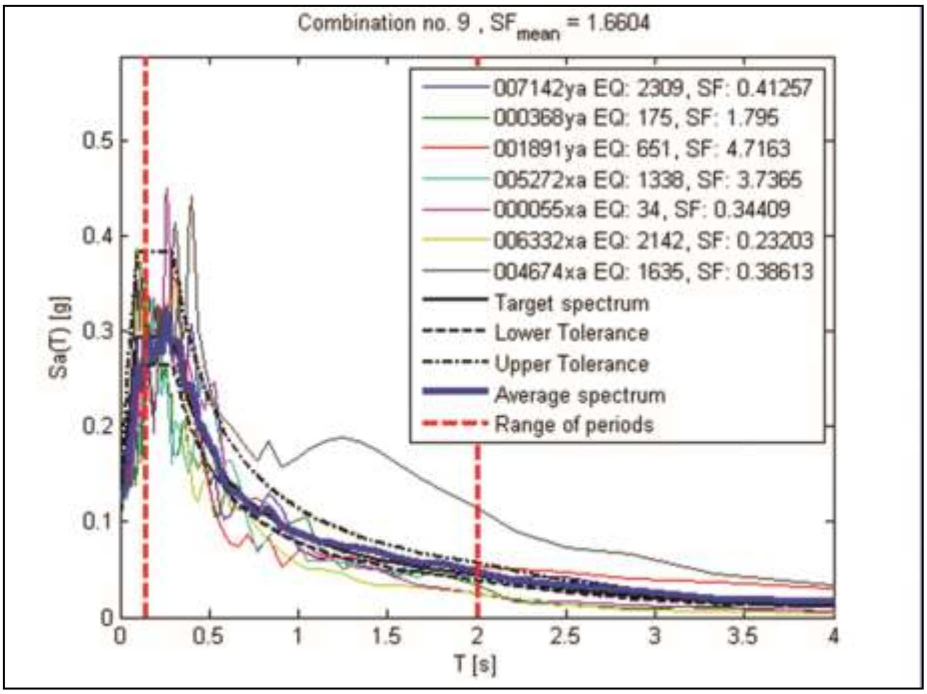

Figure 15. The Compatibility between the average spectrum obtained for 7 natural accelerometer recordings (horizontal components) and the target spectrum via the seismic response analysis at the site of San Donato - HVSR 3 for a return period of 50 years - Combination 9.

The present analysis of local seismicity was performed with one-dimensional modeling of the site using an equivalent linear model for the soil.

To evaluate the surface response of the deposit (in terms of acceleration time history, velocity, displacement, deformation or shear stresses, etc..) to an assigned seismic input applied to the base (for example accelerogram) we use the complex transfer function $F(\omega)$, a characteristic of the geometry and mechanical properties of the deposit, defined in the frequency domain. This function is able to provide qualitative information on frequency fields in which a significant amplification phenomenon of seismic motion is expected and the intervals at which the problems of attenuation can be verified. The STRATA software is used for this analysis.

The Figure. **16** and Figure. **17** show the comparison between the average spectrum obtained after propagation of 7 accelerograms recorded on rock through the profile and the spectrum expected and referenced in NTC2008 for the horizontal component of the seismic action of type C soil for HVSR 3 and type B soil for HVSR 4.

The a_{max} value was obtained in the site of San Donato HVSR 3 (Figure. **16**) through the analysis of the local seismic response 1D, therefore,

$$a_{max} = 0.2234219 \text{ (g)}$$

At this value, which only takes into account 1D stratigraphic effects, we must add the contribution of topographic amplification S_T which is equal to 1.0 at S. Donato - HVSR 3 for T1 category topography.

The horizontal and vertical seismic coefficient values for SLV are **kh = 0.0536; kv = 0.0268.** The obtained values are much higher than those calculated using the simplified method to categorize sub-soils (K_h=0,044; K_v=0,022).

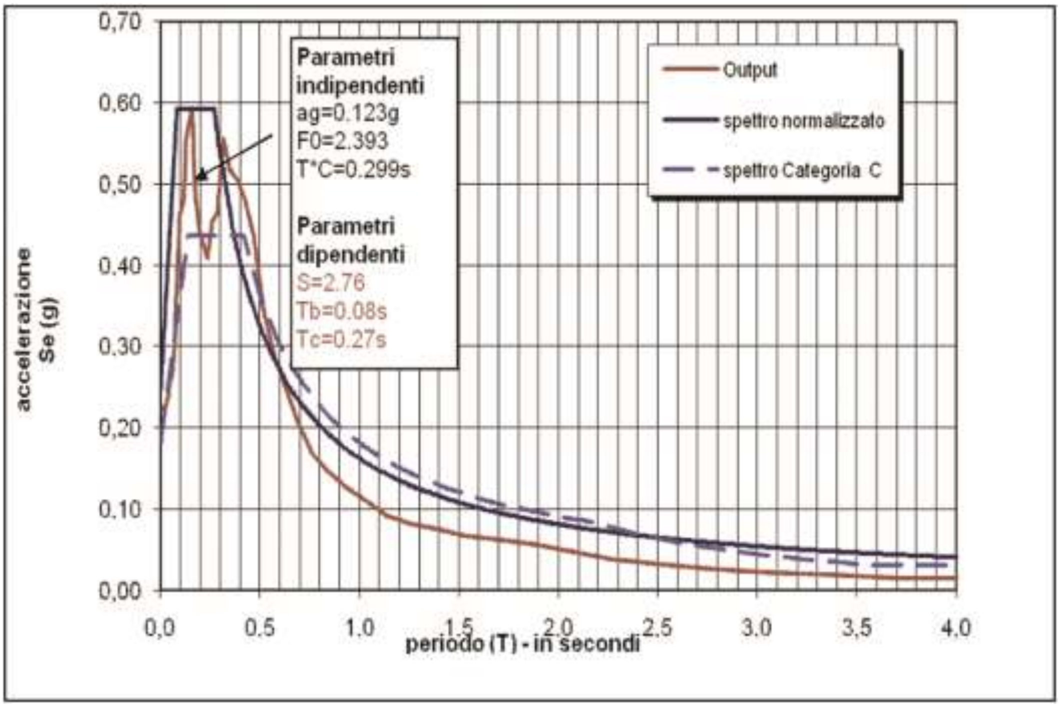

Figure. 16. Normalized Elastic spectrum for the state life safety limit of S.Donato - HVSR 3.

The a_{max} value was obtained in the site of San Donato HVSR 4 (Figure. 17) through the analysis of the local seismic response 1D, therefore,

$$\mathbf{a_{max} = 0.1657050\ (g)}$$

At this value, which only takes into account 1D stratigraphic effects, we must add the contribution of topographic amplification S_T which is equal to 1.0, at S. Donato - HVSR 4 for T1category topography.

The horizontal and vertical seismic coefficient values for SLV are **kh = 0.039 ; kv = 0.0198.**

The results of HSVR 5 and HVSR 6 are respectively identical to those of HVSR 4 and HVSR 3.

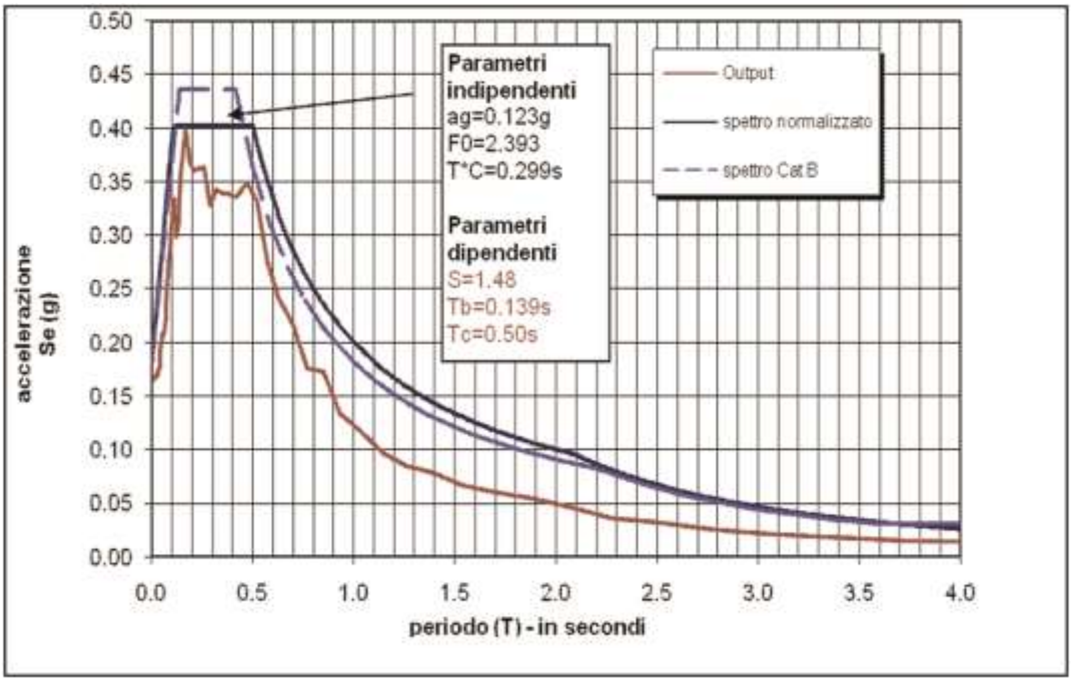

Figure. 17. Normalized Elastic spectrum for the state life safety limit of S.Donato –HVSR4.

5. Conclusion

The comparison between the subsoil categories obtained with the different approaches (HVSR, CPT, MASW, SPT) (Table 8, Figure 8, Figure 9) highlights how a site classification can be unique and depend on the method adopted. Indeed the use of indirect methods to estimate *Vs* through empirical correlations must be, as far as possible, avoided due to uncertainties. Therefore, as noted in the NTC2008, it is strongly recommended to perform the classification based on *Vs* direct in situ measurement to define the seismic action, and in our case it was performed through geophysical seismic surveys like HVSR and MASW.

Probing	$N_{SPT,30}$	N_{SPT} subsoil category	$V_{S,30}$ (HVSR)	Subsoil category (HVSR)	Formations
S5D	76	B	505	B	Olistostroma of Macigno
S7D	60	B	366	B	Meleto Clays
S8D	11	D	196	C	Deposits of filling
S9D	10	D	196	C	Deposits of filling

Table 8. Subsoil categories of using different geophysical methods.

Although operating in favor of safety in the subsoil category location, it is worth considering that S. Donato site is mostly composed by Macigno Formations (Sandstones) and Meleto Clays;

The local seismic response evaluation using 1D analysis allows defining a realistic stratigraphic seismic response of the soils not affected by two-dimensional problems (both underground and topographic). This approach is considered to be the NTC 2008 official standard. It allows, in certain cases by comparing it to the corresponding subsoil category, to obtain the saving elements while the simplified approach of the standard (subsoil categories) identifies ranges of amplification for periods usually more limited than those listed in the standard.

In some cases (for example a seismic substrate with a depth of 100m above the ground level and absence of major *Vs* contrasts in the seismic coverage) the level of amplification, or the spectrum response *Se(g)* ordinate is less than what can be deduced from using subsoil categories and in others this does not occur because the values derived from RSL.

Site	$V_{S\,30}$ - Cat. subsoil		S_T	$a_{max\ rsl}$	kh_{rsl} (SLV)	kv_{rsl} (SLV)
MASW ST_12	747 m/s	B	1.2	0.177	0.043	0.021
HVSR 3	325 m/s	C	1	0.22	0.0536	0.0268
HVSR 4	450 m/s	B	1	0.165	0.039	0.0198
HVSR 5	475 m/s	B	1	0.165	0.039	0.0198
HVSR 6	230 m/s	C	1	0.22	0.0536	0.0268

Table 9. Obtained Data from the seismic response analysis of various sites investigated with RSL method.

Site	$V_{S\,30}$ - Cat. subsoil		S_T	$a_{max\ rsl}$	kh_{rsl} (SLV)	kv_{rsl} (SLV)
MASW ST-12	747 m/s	B	1.2	0.173	0.042	0.021
HVSR 3	325 m/s	C	1	0.18	0.044	0.022
HVSR 4	450 m/s	B	1	0.144	0.035	0.018
HVSR 5	475 m/s	B	1	0.144	0.035	0.018
HVSR 6	230 m/s	C	1	0.18	0.044	0.022

Table 10. Obtained data from the subsoil category analysis through the simplified approach.

Research plan

This article is the first step towards research and I'll later focus on geophysical studies on virgin areas in my country "Morocco" and try to interpret them and come up with new hypothesis and ideas related to tectonic regimes, ore deposits, agriculture by determining the soil classification based on water strata within the first 30m… as well as lithological and seismic mapping by integrating the different results of geophysical, geomorphologic, geotechnical, hydrogeological and geological surveys at a regional scale and studying the seismicity of some known regions by their susceptibility to earthquake in the civil engineering.

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Strong Motion Databases **:** European Strong Motion Database: http://www.isesd.cv.ic.ac.uk; PEER Strong Motion Database: http://peer.berkeley.edu/smcat/search.html.