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Project S4: ITALIAN STRONG MOTION DATA BASE

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Deliverable # D13

Identification of new site parameters for improved seismic classification criteria

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1. Introduction

The most recent seismic codes have recognised the significant role of site effects on earthquake ground motion and included them in the definition of the seismic action for design. Since the early 90s (Borcherdt, 1994) the weighted average of the shear wave velocity over the uppermost 30m, $Vs_{,30}$, has become a globally accepted parameter for the classification of a site in terms of its seismic response (ENV 1998; CEN 2004; BSSC, 2003; see Deliverable 12 this project).

The determination of the shear-wave velocity profile is not often a common practice, because of the high costs involved, and the classification of a site is frequently based on the geological / geotechnical characterization of the shallowest layers.

The quantitative characterization of the sites of the Italian strong-motion network, in terms of $Vs_{,30}$, is quite unsatisfactory (45 stations characterized in 2007 and about 50 will be added at the end of this project) so that alternative site parameters should be identified to characterize a site, with the aim of deriving GMPEs for the Italian territory.

The assessment of the best parameters for the improvement of the site classification actually provided by the seismic norms is beyond the aim of the S4 project, however, the outcome of this task is to provide parameters alternative to $Vs_{,30}$, obtained with low cost methods, usable for alternative site classifications.

This task is developed as follows:

1. classify the sites of the Italian strong-motion stations according to the classes of the Eurocode 8 and the Italian seismic code, on the base of quantitative data and geological and geotechnical considerations (in collaboration with Task 2);
2. provide a set of parameters suitable for alternative site classifications, some of them obtainable from low cost investigations, to include in the ITACA database;
3. test different classification through the performance of Ground Motion Prediction Equations in terms of standard deviation.

Within the first activity, the classification of the Italian strong motion stations, according to the Eurocode 8 (or Italian seismic norms), is achieved in two ways: i) evaluation the average shear wave velocity in the uppermost 30m available from geophysical tests executed before or within the project (in total about 100 sites); ii) inference of the EC8 classes from the Italian geologic map at 1:100,000 scale (see Deliverable 2, this project).

Parameters alternative to $Vs_{,30}$ should be defined, as the effectiveness of $Vs_{,30}$ as the best estimator of the seismic response of a site is under debate since a decade (see Deliverable 12, this project). It has been demonstrated that in particular cases, such as in presence of deep basins or velocity inversions, this parameter is not related to the real amplification of the site or that alternative estimates, such as $Vs,_{10}$ (average shear wave velocity in the uppermost 10m) could have the same performance at lower costs (Steidl, 2000; Park and Hashash, 2004; Stewart et al., 2003; Di Giacomo et al., 2005; Gallipoli and Mucciarelli, 2009, among others).

The following parameters, that may be correlated to the seismic response of a site, were selected:

- average shear wave velocity in the first 30 m ($Vs,_{30}$);
- average velocity to the bedrock depth ($Vs,_{bed}$);
- average shear wave velocity at different depths ($Vs,_{H}$);
- depth to bedrock;
- resonant frequency obtained from H/V of earthquake records (f_{0hvsr});
- resonant frequency obtained from H/V of noise records (f_{0nhvsr});
- resonant frequency obtained from 1D models (f_{01D});
- resonant frequency obtained from H/V of acceleration response spectra (f_{0nhvrs});
- amplitude at f_{0hvsr};
- amplitude at f_{01D};
- amplitude at $f_{0hvrs;}$

We collected a set of well documented recording stations, characterized by geophysical and geotechnical investigations, merging two data sets: a set of 63 station belonging to the RAN and a set of 25 stations investigated by the University of Basilicata (see Appendix 1).

All the selected stations had a quantitative measure of the shear wave velocity with depth, mostly obtained with invasive techniques, such as down-hole or cross-hole. Only two profiles did not reach 30m (stations Nocera Umbra, NCR, and Tarcento, TRC) as the bedrock was encountered before that depth.

The rest of the parameters were not always available for the selected stations. The depth to bedrock and the average Vs to bedrock, in particular, can be determined only at high costs with invasive techniques in case of large depths. Non invasive techniques cannot estimate with sufficient accuracy the soil / bedrock boundary in case of for large depths or lack of strong impedance between the superficial layers and the bedrock.

A parameter that can be determined with enough accuracy and at low costs is the resonant frequency or, in alternative, the predominant frequency of the soil. Either can be estimated with horizontal to vertical spectral ratios (HVSR) of ambient noise measurements or earthquake recordings, although the variability of the results associated to the latter is larger, due to the different seismic source characteristics or the site-to-source orientation. The amplitudes of HVSR at the resonant peak or predominant peak might be helpful, although they do not reproduce the true amplification of the site. As alternative, we calculated the horizontal to vertical ratio of acceleration response spectra (HVRSR) evaluated at 5% damping.

We examined the data set and we eliminated the sites which had a no reliable Vs profiles, such as S. Giuliano di Puglia scuola, among others. Then we considered only the stations with a useful number of recordings (ambient noise or earthquakes) to calculate reliable H/V curves.

2. Cluster analysis

We wanted to follow a data driven approach for site classification and we decided to perform a cluster analysis – where clustering or cluster analysis (Tryon, 1939), is a multivariate technique for the selection and group homogeneous elements into a sample -. All clustering techniques are based on the concept of distance from elements, so that the membership to a group depends on the distance of one element from the centre of the group.

We selected a set of well characterized soil sites and tried different combinations of number of groups and parameters. The combination obtained selecting $Vs_{,30}$ and fundamental frequency, obtained by the H/V of response spectra, and 3 groups gave the mean and standard deviation for each class and parameter as listed in Table 1. In Figure 1 the points are plotted in the space frequency – $Vs_{,30}$. In Table 2 and Figure 2 the results obtained in case of four clusters are shown. In general the lower distances are obtained considering 4 clusters. The largest distances from points to the centre of the group are obtained for classes 2 and 3, considering three or four clusters. These classes contain the largest number of outliers, such as the stations with low fundamental frequencies and high $Vs_{,30}$ (i.e. AQK, L’Aquila parking), or stations with high fundamental frequency and intermediate $Vs_{,30}$ (i.e. L’Aquila valle Aterno, AQA, Tarcento, TRC, and Pachino, PCH).

Table 1: $Vs_{,30}$ and f_0 mean and standard deviation for three clusters (*dist* is the normalized distance from the centre of the cluster).

Class	**mean $Vs_{,30}$**	**std $Vs_{,30}$**	**mean f_0**	**std f_0**	**Dist**
1	287.8588	82.2083	1.0576	0.4969	1.3026
2	470.5540	76.3074	2.5767	0.9544	1.2518
3	575.2493	92.1431	6.3571	1.6978	1.1429

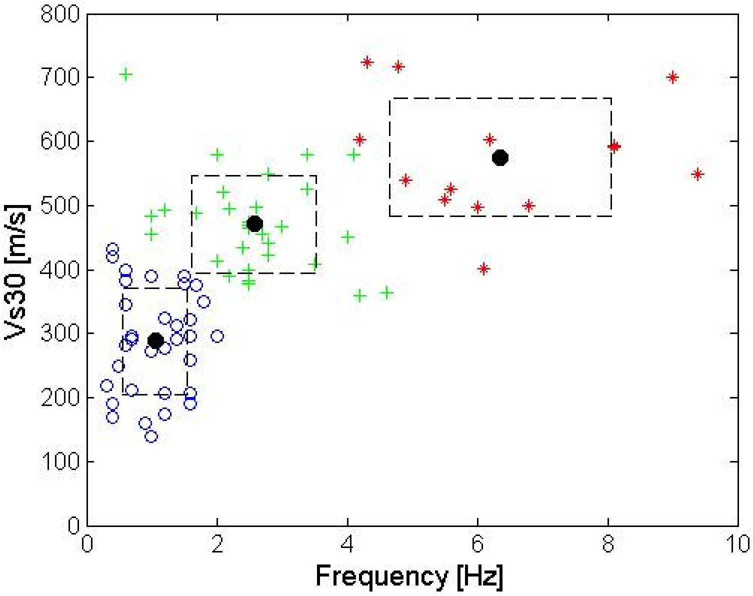

Figure 1: three clusters obtained from the observations (the boxes indicate mean +/- 1 std)

Table 2: $Vs_{,30}$ and f_0 mean and standard deviation for four clusters (*dist* is the normalized distance from the centre of the cluster).

Class	**mean $Vs_{,30}$**	**std $Vs_{,30}$**	**mean f_0**	**std f_0**	**Dist**
1	249.3058	59.2480	1.0583	0.4781	1.2745
2	447.7461	71.4526	1.9121	0.8455d	1.2493
3	529.8969	106.4234	4.8812	1.0387	1.3192
4	608.0350	64.4916	8.6500	0.6557	1.1852

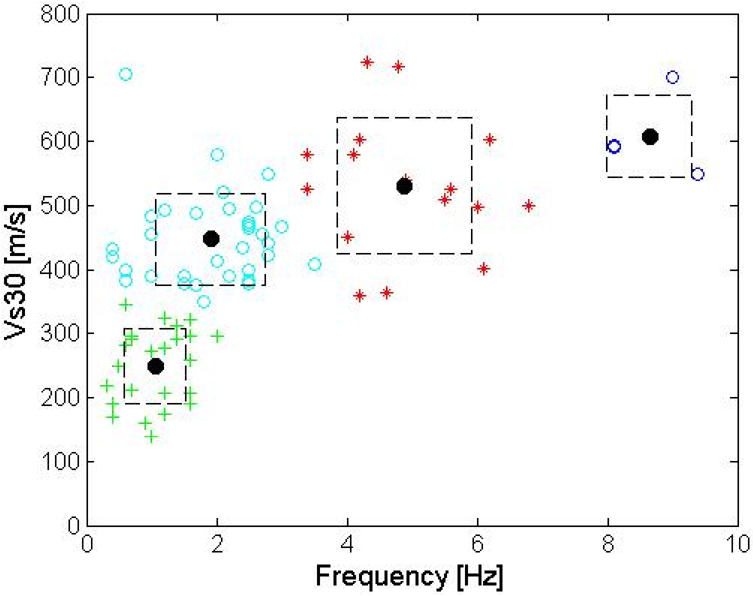

Figure 2: Four clusters obtained from the observations (the boxes indicate mean +/- 1 std)

Low distances from the centre of the clusters are also obtained using the fundamental frequency to group the observations. The fundamental frequency associated to the third class is higher than in the case $Vs_{,30}$ - f_0, as listed in table 3 and shown in Figure 3.

Table 3: f_0 mean and standard deviation for each class.

Class	Mean f_0	Std f_0	Dist_f_0
1	1.1341	0.5285	1.2285
2	3.2269	0.8702	1.2381
3	7.0800	1.4459	1.2110

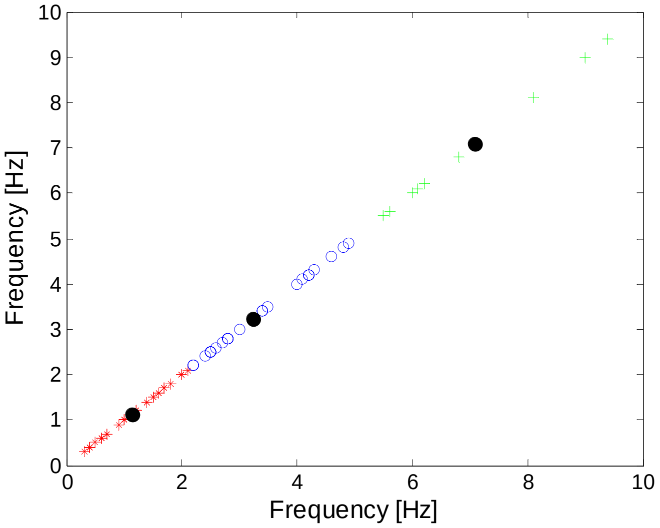

Figure 3: three clusters obtained from fundamental frequency (different colours indicate different classes, black dots are the cluster centres)

If we assume that the variables characterizing each class, i.e. the couple [$Vs_{,30}$, f_0] or the single f_0, are normally distributed with mean μ and standard deviation σ, the degree of membership of a specific observation is evaluated as probability density for each class.
For a N variable normal distribution, the probability density function is:

$$f(x) = \frac{1}{(2\pi)^{N/2}|\Sigma|^{1/2}} e^{-\frac{1}{2}(x-\mu)^T \Sigma^{-1}(x-\mu)} \qquad (1)$$

$$\mu = [\mu_1, \mu_2, ...\mu_N]^T \qquad (2)$$

where μ is the vector of the variable mean and Σ is the covariance matrix.
The site is assigned to the class with the highest probability density. Figure 4 shows the probability density associated to the classes with the characteristics of table 1, while Figure 5 displays the values associated to the classes with the characteristics of table 2.
Figure 6 shows the probability density curves associated to the classes, identified by the fundamental frequency, as listed in table 3.

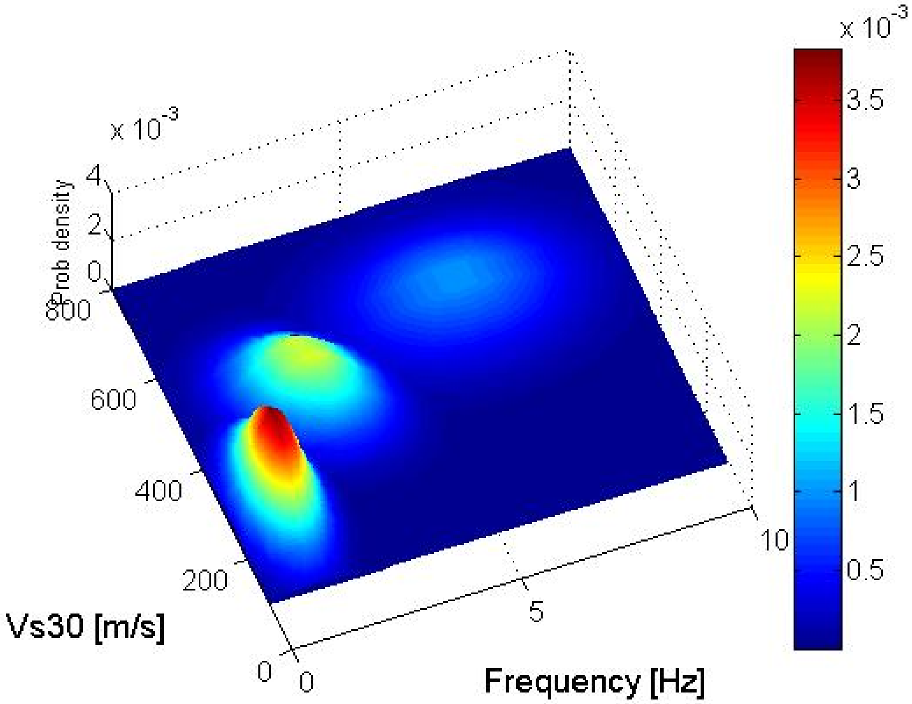

Figure 4: probability density calculated for the three classes identified on the base of Vs,30 and fundamental frequency (table 1).

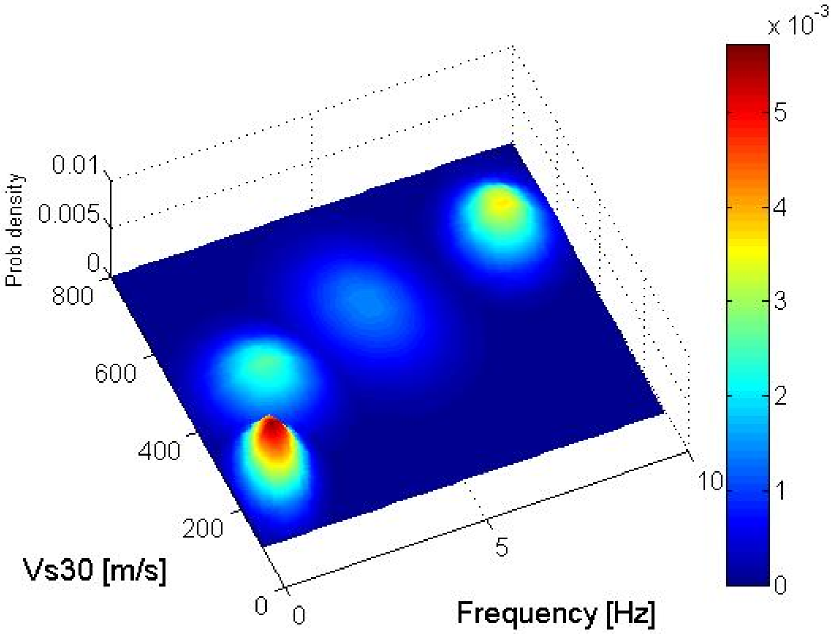

Figure 5: probability density calculated for the four classes identified on the base of Vs,30 and fundamental frequency (table 2).

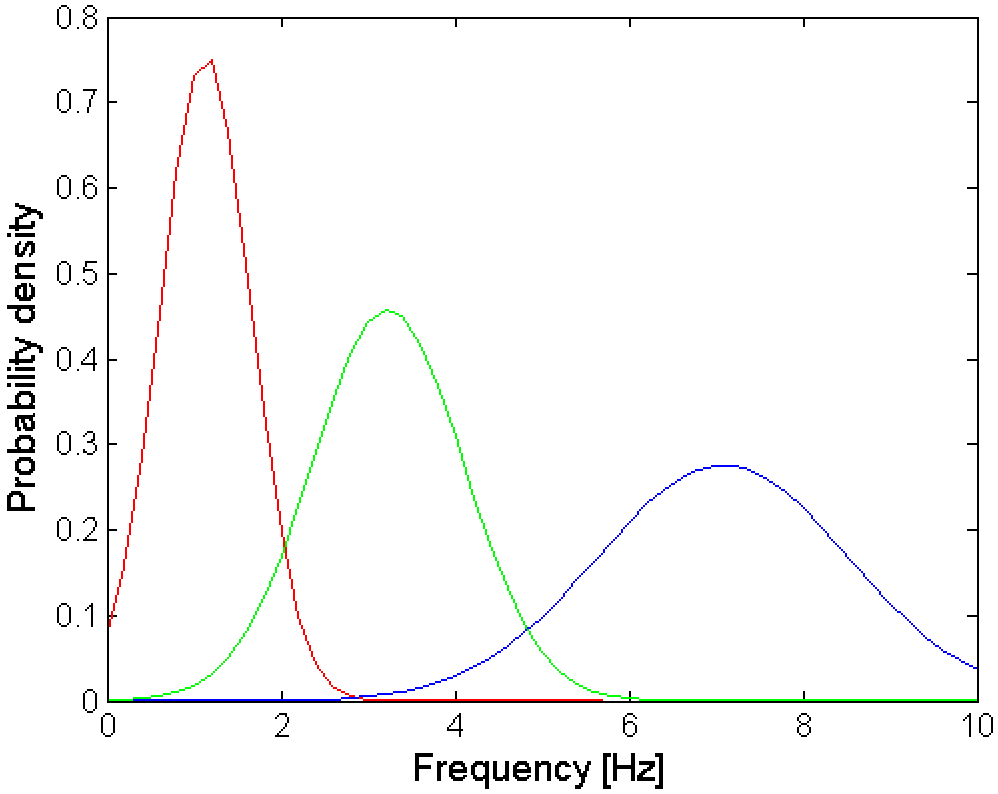

Figure 6: probability density calculated for the three classes identified on the base of fundamental frequency (table 3).

4. Derivation of a soil classification

In paragraph 2 we derive that recording stations having Vs,$_{30}$ < 800 m/s and a well defined seismic response, in terms of fundamental frequency, tend to group in three / four classes. Nevertheless, we did not consider rock sites in the cluster analysis, as the H/V curve of these sites has no evident peaks, but a rather flat response in the entire frequency band (Figure 7). Sites with similar response were included in a fourth class.

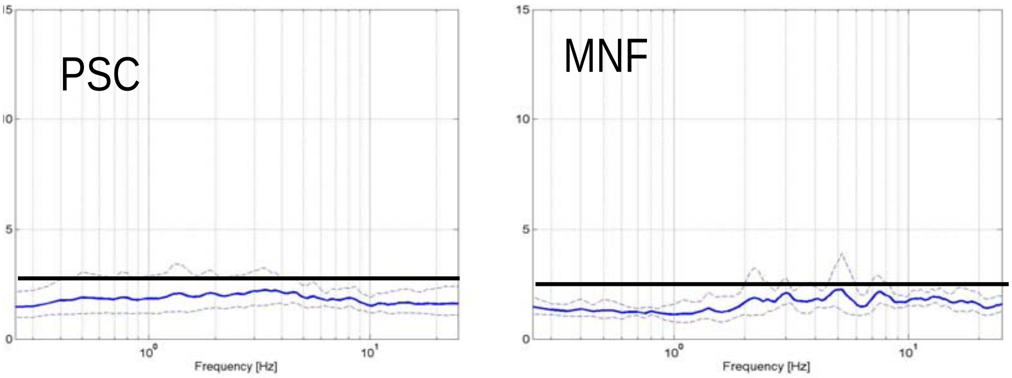

Figure 7: H/V from response spectra for two rock sites: Pescasseroli (PSC), on the left, and Monte Fiegni (MNF), on the right (the thick black line indicates the response expected for a standard rock site)

During the phase calculation of the H/V curves from the acceleration response spectra of the stations belonging to the Italian strong motion network, the could observe that several stations had no clear peaks in the H/V curve, so that a distinct fundamental frequency could not be identified. The response was a rather broad band amplification with multiple peaks and average amplitude greater than 2.7 for a wide frequency range, as shown in Figure 8. Sites with this kind of response were assigned to a fifth class.

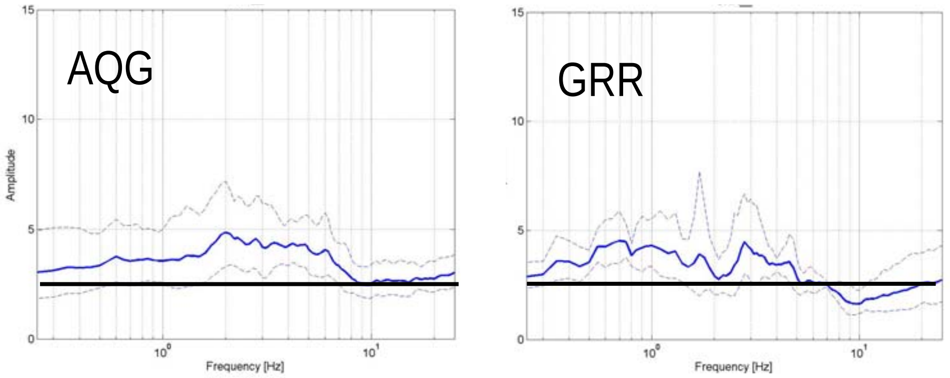

Figure 8: H/V curves with broad band amplification: station L'Aquila Valle Aterno Colle Grilli (AQG), on the left, and Giarre (GRR), on the right.

In summary, we propose a classification made of 5 classes: i) 3 soil classes identified on the base of the fundamental frequency, as in Table 3; ii) 1 soil class identified from the broad band amplification of the H/V curve and iii) 1 rock class, identified on the base of the flat H/V response.

4. Test of the performance of different soil classifications in GMPEs

In order to test the performance of different classification schemes, GMPEs are evaluated for acceleration response spectra, calculated at 5% damping.

We selected four classification schemes proposed in the literature or in seismic codes:

1. classification proposed in the EC8 seismic norms, essentially based on the $Vs_{,30}$ intervals, with the exception of class E, which is based on the combination of $Vs_{,30}$ and depth to bedrock (table 4);
2. classification proposed by Sabetta and Pugliese (1987), hereinafter SP87, for deriving a set of predictive equations for Italy (table 5);
3. classification proposed by Di Alessandro et al. (2008), hereinafter DIAL08, based on the predominant frequency of the soil obtained by the horizontal to vertical spectral ratio of the acceleration response spectra (table 6);
4. classification developed in this task, hereinafter S4T5, described in paragraph 3 and Table 7.

A GMPE is derived for each classification using the same data set and functional form and the performance is evaluated in terms of standard deviation of the GMPEs.

Table 4: soil classification according to the Eurocode 8

Subsoil class	**Description of stratigraphic profile**	**Parameters**		
		$V_{s,30}$ (m/s)	N_{SPT} (bl/30cm)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5m of weaker material at the surface	> 800	–	–
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of m in thickness, characterised by a gradual increase of mechanical properties with depth	360 – 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of m	180 – 360	15 - 50	70 – 250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with $V_{s,30}$ values of class C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with $V_{s,30}$ > 800 m/s			
S_1	Deposits consisting – or containing a layer at least 10 m thick – of soft clays/silts with high plasticity index (PI > 40) and high water content	< 100 (indicative)	–	10 – 20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in classes A –E or S_1			

Table 5: soil classification according to Sabetta and Pugliese (1987)

Subsoil class	Description	Parameters
0	Rock	Vs > 800 m/s
1	Stiff, shallow alluvium	400 < Vs < 800 m/s depth < 20m
2	Deep alluvium	400 < Vs < 800 m/s depth > 20m

Table 6: soil classification proposed by Di Alessandro et al.(2008)

Subsoil class	Description	Parameters
SC-I		T <0.2
SC-II		0.2 >= T < 0.4
SC-III		0.4 <= T < 0.6
SC-IV		T >= 0.6
SC-V	Rock sites	Flat response
SC-VI		T unknown
SC-VII		T unknown

Table 7: soil classification proposed in this task

Subsoil class	Description	Parameters
1	Pd1 > Pd2 > Pd3	mean f_0 = 1.1341; std f_0 = 0.5285
2	Pd2 > Pd1 and Pd2 > Pd3	mean f_0 = 3.2269; stdf_0 = 0.8702
3	Pd3 > Pd1 and Pd3 > Pd1	mean f_0 = 7.0800; std f_0 = 1.4459
4	Flat response amplitude < 3 over the entire range	
5	Multiple peaks and amplitude > 3 over a broad period range (0.1 – 1 s)	

The common data set used to derive the GMPE is derived from the ITACA database, where the recording stations have been classified according to each of the schemes proposed. Figure 9 shows the magnitude distance distribution of the set. The minimum magnitude is 3.5 and the maximum distance is 300km. The data set includes 13 events of the recent L'Aquila seismic sequence dated 6 April 2009.

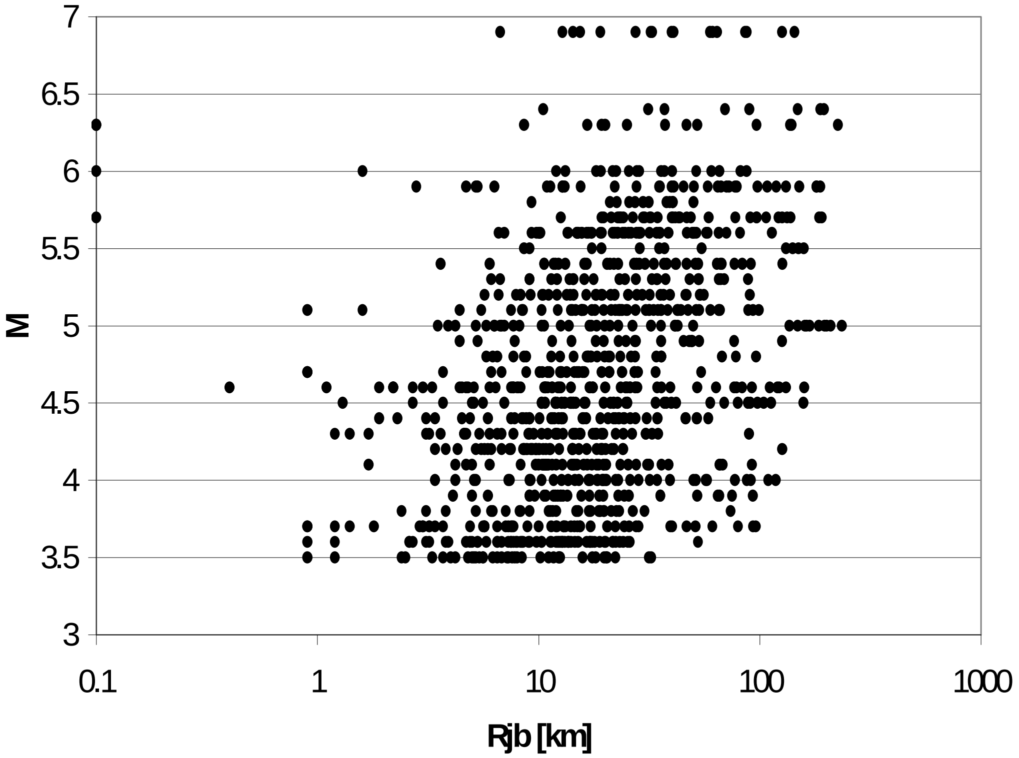

Figure 9: magnitude – distance distribution of the data set used to derive the GMPE of this study

The results of the application of each classification is shown in table 8, where the number of stations belonging to each class is shown for each of the adopted schemes. It should be noted that the classifications based on the spectral ratio between the horizontal and vertical components of response spectra (DIAL08 and this study) are the most selective in the classification of rock sites.

Table 8: number of recording stations for each class of the schemes adopted (in bold rock sites)

Ec8	$Vs_{,30}$	Nsta		SP87	Vs – depth	Nsta
	A	**89**			**0**	**79**
	B	46			1	48
	C	34			2	51
	D	3				
	E	6				
S4T5	f_0	Nsta		DIAL08	f_{max}	Nsta
	1	45			Class I	26
	2	42			Class II	36
	3	23			Class III	18
	4	**38**			Class IV	27
	5	26			**Class V**	**22**
					Class VI	19
					Class VII	30

The functional form used for the regression is:

$$\log_{10} Y = a + f(M) + g(R) + e_i S_i + f_j F_j \tag{3}$$

where

$$f(M) = b_1 \left(M_W - M_{ref}\right) + b_2 \left(M_W - M_{ref}\right)^2 \tag{4}$$

and

$$g(R) = \left[c_1 + c_2\left(M_W - M_{ref}\right)\right] \log_{10}\left(\sqrt{\left(R_{JB}{}^2 + h^2\right)} / R_{ref}\right) + k\left(\sqrt{\left(R_{JB}{}^2 + h^2\right)} - R_{ref}\right) \tag{5}$$

The response variable is the geometric mean of the horizontal component of the acceleration response spectrum evaluated at 5% of damping, while the reference magnitude M_{ref} is 5.6 and the reference distance R_{ref} is 1km.

We used the random-effect regression model by Brillinger and Preisler (1985).

Given an earthquake *i* recorded at the station *k*, we have:

$$\log y_{ik} = \mu_{ik}\left(M_i, R_{ik}, ..., V_{S30}\right) + \theta_k + \xi'_{ik} \tag{6}$$

θ is the inter-station distribution of error which assumes a value for each station and describes the correlation among the errors for different recordings at the same station. It is assumed to be normally distributed with standard deviation equal to δ.

ξ' is the intra-station distribution of error which assumes a value for each recording. It is also normally distributed with standard deviation equal to σ'.

The error distributions δ and ξ' are assumed to be independent, so that the residuals can be decomposed as the sum of the inter- and intra-event error distributions, as:

$$\mathrm{Re}\,sidual_{ik} = y_{ik} - \mu_{ik}\left(M_i, R_{ik}, ..., V_{S30}\right) = \theta_k + \xi'_{ik} \tag{7}$$

Since the distributions are independent, the total variance is the sum of the two variances as:

$$\sigma_{tot}^2 = \sigma^2 + \delta^2 \tag{8}$$

Figure 10 visually shows the contribution of the different sources of error for an event of magnitude 5.5 and acceleration spectral ordinates equal to 1.75s. This example explains the behaviour of three stations of the ITACA database (GPB, AVZ and CLC) which belong to the same soil class (in this case the EC8 classification is adopted). The black line shows the median prediction for the class, while the coloured lines are the median values for each station (median of the class plus the inter-station error). The intra-station errors are defined as the difference between the observations and the median value for each station.

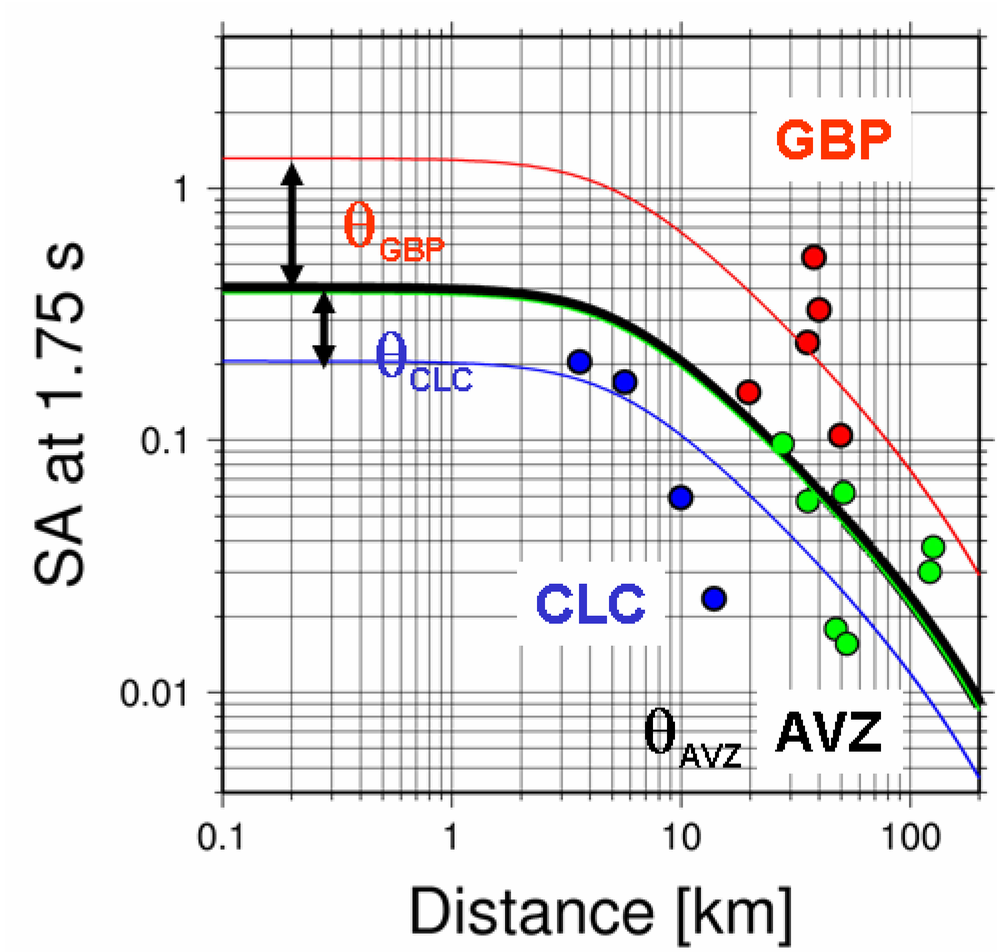

Figure 10: inter-station errors θ at Gubbio Piana (GBP), Avezzano (AVZ) and Colfiorito Casermette (CLC). The inter-station error of station AVZ is close to zero, so that the prediction for this station is approximately equal to the median of its class.

All the coefficients obtained from the regression are not shown in detail, because we will focus only on the coefficients relative to the soil classes. Figures 11a-d show the soil coefficients in function of period for the four classification considered. The classification SP87 considers only 2 soil classes which are well separated, so this classification can be considered rather efficient (Figure 11a). EC8 accounts for 4 soil classes, two of them representing sites with well defined response, classes D and E, while classes B and C tend to be very similar especially at low periods (Figure 11b).

The classification DIAL08 accounts for six soil classes, 2 of them with a well defined response (classes I and IV), while classes II and III have intermediate response although too similar (0.2 - 0.4s and 0.4–0.6 s are the respective period intervals) and, finally, coefficients of classes VI and VII are also very similar (Figure 9c). The classification proposed in this study (S4T5) considers four soil classes, three of them, which are well defined, are identified on the base of the fundamental frequency, while the fourth, characterized by broad band amplification, assumes moderate values at all frequencies. It should be noted that there is a common characteristic to all classification, that is all soil coefficients tend to be very similar in the period interval 0.2 – 0.4s.

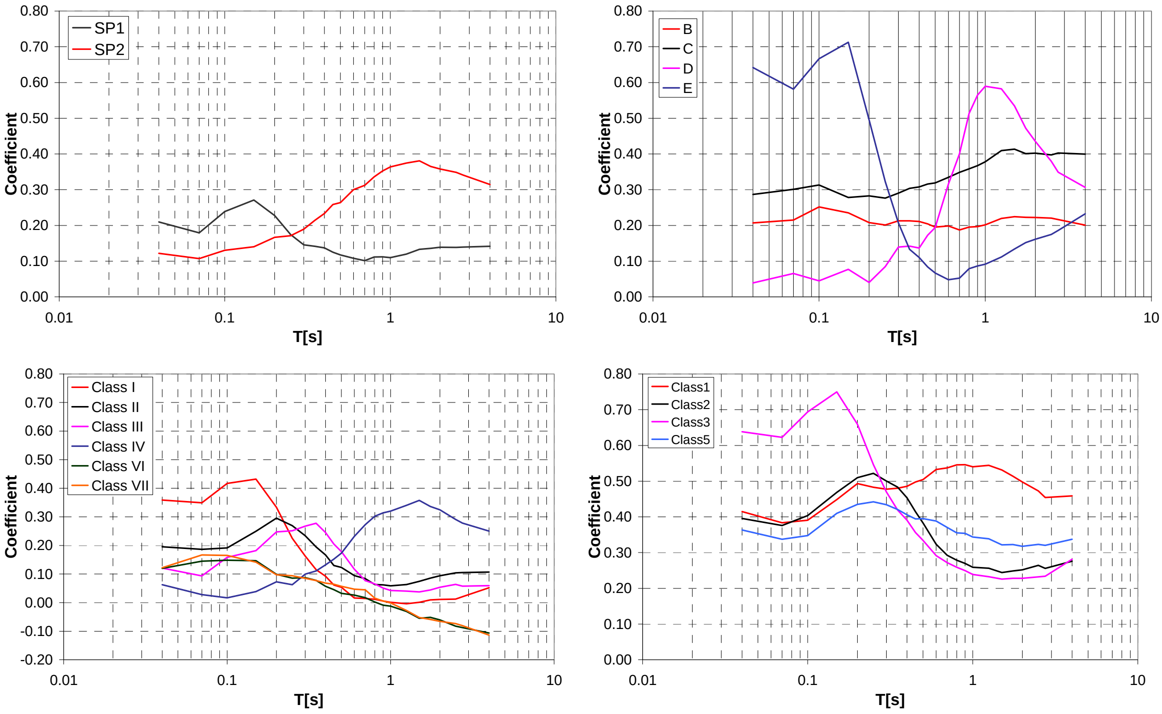

Figure 11: soil coefficients obtained by regression a) Sabetta and Pugliese (1987); b) Eurocode 8; c) Di Alessandro et al. (2008); d) this study.

Finally, the error associated to each GMPE is taken into account, in terms of total standard deviation (σ_{tot}) and contribution to the standard deviation due to the recording sites (σ_{sta}). Figure 12 shows the variation in the total standard deviation due to different classifications. As extreme cases we reported the standard deviation obtained with no classification and the standard deviation obtained with the simplest binary classification (either soil or rock). As expected, the lack of soil classification increases the standard deviation at all periods. In the period range 0.04 to 0.3s the simple soil / rock distinction seems sufficient to obtain low values of the standard deviation, even lower than those obtained with detailed classifications. At periods larger than 3s there is an inversion of this trend and a more accurate site classification reduces the standard deviation. In this case the classifications which distinguish different levels of amplification in this period range works better (i.e. EC8, DIAL08, S4T5). In the period interval 0.2 – 0.4s, where all soil coefficients tend to be very similar, there is the largest variability in the standard deviation. If the standard deviation related to the site is examined, we observe that the largest contribution to the total standard deviation is attributable to the site is in the range 0.04 -0.2s, while at periods larger than 0.3 the site contribution becomes less relevant (Figure 13).

In particular, this trend can be observed in detail in Figure 14, where the total, the inter-station and the intra-station standard deviations are shown for the classification scheme proposed in this study.

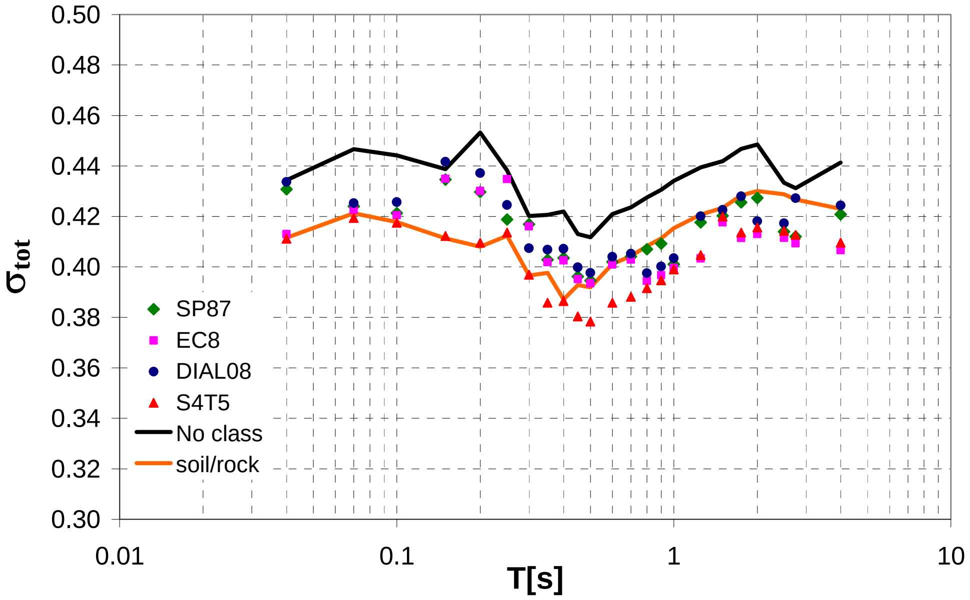

Figure 12: total standard deviation associated to different soil classifications

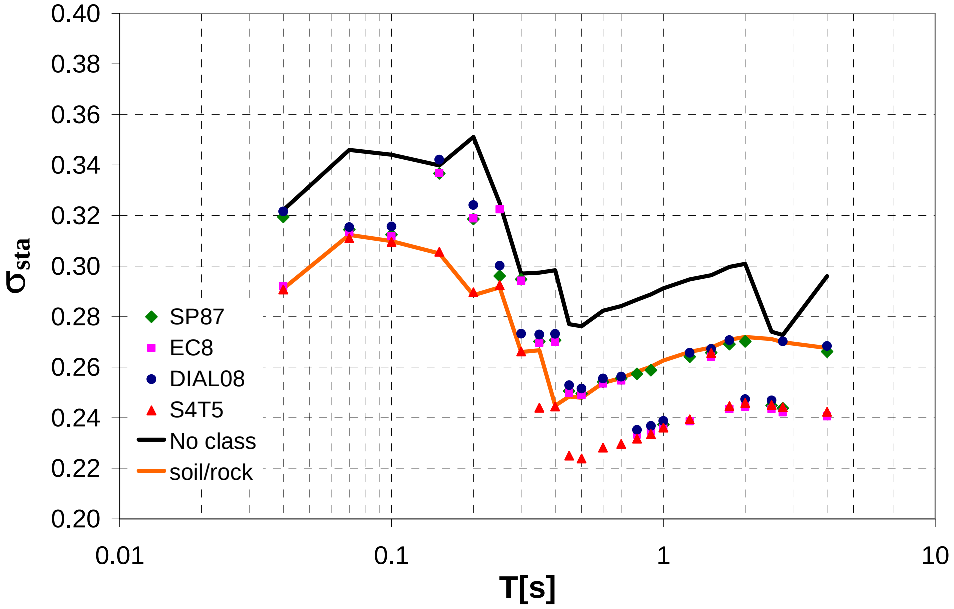

Figure 13: inter-station standard deviation associated to different soil classification

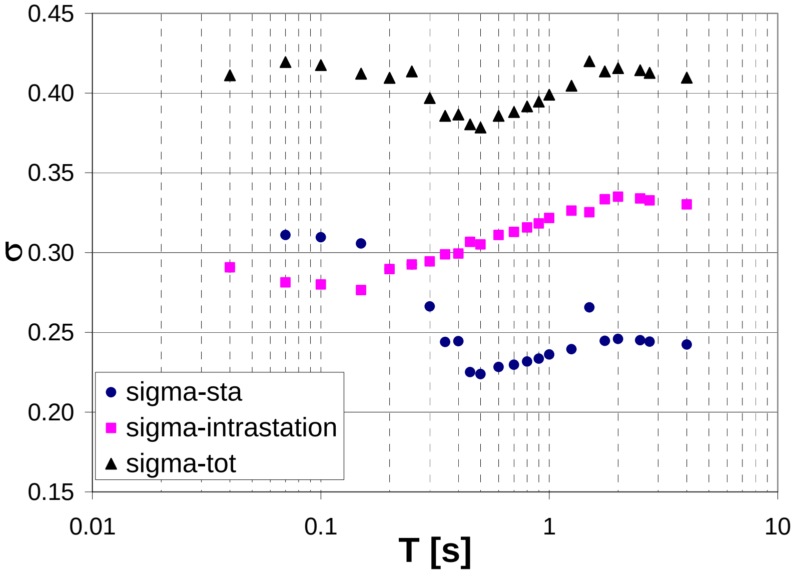

Figure 14: total, inter-station and intra-station sigmas obtained with the soil classification proposed in this study.

Appendix 1: data set of recording stations characterized by geophysical and geotechnical data (bb = broad band H/V curve; flat H/V curve)

Station name	**Net**	**Ec8**	**$Vs_{,5}$**	**$Vs_{,10}$**	**$Vs_{,15}$**	**$Vs_{,20}$**	**$Vs_{,25}$**	**$Vs_{,30}$**	**$Vs_{,bed}$**	**$H_{,bed}$**	**f_{0hvsr}**	**f_{0nhvsr}**	**f_{01Dr}**	**f_{0hvrs}**
Ancona Palombina	RAN	C	209	199	217	229	243	256			1.0		1.2	1.1
Ancona Rocca	RAN	B	306	373	413	448	501	549	467	21	2.8		6.6	1.1
Argenta	RAN	D	150	150	150	153	163	170				0.4		
Arienzo	RAN	E	241	279	376	452	512	578	200	8	4.1	7.9	5.8	4.7
Assergi	RAN	B						488						3.4
Auletta	RAN	A	759	1026	1101	985	1058	1149	759	5				bb
Avezzano	RAN	C						199						0.8
Bagnoli Irpino	RAN	B	270	337	396	441	474	498	498	30	flat	11.9	5.6	flat
Bagnone	RAN	B	376	453	486	525	585	640	512	19	4.2		7.0	bb
Bazzano	RAN	B	640	640	640	640	652	679	640	23	flat			flat
Benevento	RAN	B	494	421	529	606	667	716	400	9	4.8		4.9	4.7
Bevagna	RAN	C	199	178	154	164	187	200	454	100	1.6	0.4	1.4	1.2
Bibbiena nuova	RAN	C	200	246	252	263	280	295				flat		flat
Bisaccia	RAN	A	440	690	813	871	904	997	320	3	flat			flat
Bojano	RAN	C	166	172	219	259	295	306				0.3		bb
Borgo Cerreto Campo Sportivo	RAN	B	304	356	386	420	447	486	467	28	2.5	1.2		
Borgo Ottomila	RAN	D						92			0.3			0.3
Bovino	RAN	B	179	209	254	294	340	364	285	19	4.6		4.7	flat
Brienza	RAN	B	209	272	313	341	374	402			6.1		6.7	6.0
Buia	RAN	C	155	188	213	228	239	258	307	45	1.6		2.2	1.5
Calitri	RAN	B	358	412	451	465	469	495	480	28	2.2		2.0	2.0
Caltagirone	RAN	B	221	273	319	348	368	373			flat	flat		0.4
Capestrano	RAN	B	540	600	623	645	694	730	633	19	2.7	2.7		2.7
Cassino	RAN	B						630						2.0
Catania Piana	RAN	D	110	120	124	132	147	160			0.9			bb
Cattolica	RAN	C	155	166	182	192	198	207				1.2		1.0
Cesena	RAN	B	307	373	422	463	502	540	500	25	4.9		6.6	4.0
Città di Castello	RAN	C	296	316	319	358	387	390			1.5	0.3	1.5	
Colfiorito	RAN	D	121	125	121	128	136	140	155	54	1.0	1.0	0.8	1.0
Dicomano	RAN	E	299	445	532	589	644	706	300	4		19.1	18.0	
Ecours	RAN	B	207	296	352	397	439	473						
Faenza	RAN	C	259	259	263	276	285	292			0.7	1.0		2.3

Firenzuola	RAN	C	241	184	200	247	283	312			1.4	1.6		1.5
Fivizzano	RAN	E	190	261	347	420	481	495	295	12	5.5		7.2	5.0
Forgaria Cornino	RAN	B	235	316	367	416	424	454	440	28	2.7		3.3	2.8
Forlì	RAN	C	266	265	291	297	304	295	291	45	0.7		1.6	1.3
Garigliano	RAN	C	221	206	180	178	179	191			1.6		1.4	1.8
Gela	RAN	C	211	190	197	210	229	244						
Gemona	RAN	B	262	339	381	407	423	445						1.3
Genova	RAN	A	465	691				1048	324	3		flat	29	6.0
Grumento Nuova	RAN	C	272	272	272	272	272	283			0.6	0.6		0.6
Gubbio piana	RAN	C	161	188	203	203	210	224	268	58	0.3	0.3	0.3	0.3
Ispica	RAN	A	870	1084	1180	1235		1322	338	1		flat		bb
Lagonegro	RAN	B	411	411	411	411	424	430	621	88		4.0		bb
Lasalle	RAN	B	300	340	381	427	465	496	495	30			4.0	
Lauria Galdo	RAN	B	364	433	484	512	553	603	553	25	6.2			6.2
Maiano Prato	RAN	C	279	333	359	378	369	344						bb
Maratea	RAN	A						1030						
Marsico Vetere	RAN	B						680						6.4
Mercato S. Severino	RAN	B	264	361	385	457	488	483	500	40	1.0		2.2	1.2
Modena	RAN	C	161	161	166	187	202	212				0.7		0.8
Montecassino	RAN	A						1000	200	3		18.3		
Mormanno	RAN	A						1400				flat		flat
Nocera Umbra	RAN	E	214	293	383	453	557	557	272	10	6.8	7.2	9.0	6.6
Norcia	RAN	B	368	478	560	617	657	687			0.9	0.6		0.8
Norcia Zona industriale	RAN	B	524	524	524	533	547	557	558	145	0.5	0.7		
Noto	RAN	B	324	448	535	592		658	371	7			13.0	flat
Novellara	RAN	C	164	164	172	179	185	190			0.4	0.7		0.9
Onna	RAN	B	325	325	330	349	365	378			2.3			2.7
Pachino	RAN	B	298	386	456	514	556	593	456	15			8.0	
Palazzolo Acreide	RAN	E	281	424	518	583		638	311	6		flat	11	bb
Patti (cab. ENEL)	RAN	C	155	168	198	223	242	250			0.5	3.8		0.5
Pescasseroli	RAN	A	1000	1000	1000	1000	1000	1000			flat	4.3		flat
Pieve S. Stefano	RAN	B	338	429	513	554	591	613	455	13	8.1		8.6	7.8
Pignola	RAN	B						430						
Pinerolo	RAN	B	214	276	325	357	379	383						bb
Ragusa	RAN	A	541	746	854	920		999	297	2		1.2		0.8

Rieti	RAN	D						170			0.6			0.6
Rionero in Vulture	RAN	B	397	407	448	485	507	538	525	28	flat		5.0	bb
Ronco Scrivia	RAN	B	403					684	303	3		flat		
S. Casciano dei Bagni	RAN	E	243	278	340	413	475	485	306	13		5.8	6.0	
S. Giuliano centro	RAN	B	400	500	571	645	720	781	400	6	2.2		9.2	bb
S. Severo	RAN	B	308	343	355	367	381	390			2.2		1.3	2.3
Sansepolcro	RAN	C	327	288	276	319	316	322						bb
Sannicandro Garganico	RAN	A	889	957	978	1026	969	965						bb
Santa Croce Camerina	RAN	A	425	625	742			865	297	3			20	bb
Santarcangelo	RAN	B	369	369	369	391	411	420	693	140		0.3		flat
Satriano di Lucania	RAN	B						390			flat			flat
Scanno	RAN	A	750	750	750	750	500	840	750	20		3.6		10.0
Sellano est	RAN	B	211	279	334	378	426	520	378	20	2.5	1.8	7.3	2.5
Sellano ovest	RAN	B	193	267	332	389	440	518	367	18	1.7	1.2	7.2	bb
Sestri Levante	RAN	B	249	367	436			540				flat		3.49
Spezzano della Sila	RAN	C	200	206	230	250	285	320	304	28	3.0	3.4		2.7
Sturno	RAN	B	244	264	296	333	357	382	380	30	2.5	flat	4.0	bb
Tarcento	RAN	A	300	578				901	390	4	9.0		9.8	8.6
Tolmezzo	RAN	B	308	366	390	403	467	522	403	20	2.1		4.1	2.2
Torre Faro (Me) Cab. ENEL	RAN	C	128	176	204			242						
Torre Pellice 2	RAN	B						547						
Torre Pellice 7	RAN	C						286						
Tortona	RAN	E	221	290	366	427	474	483	304	11			6.0	5.9
Tortorici	RAN	B	365	402	376	423	489	525	378	17		5.62	5.0	bb
Tricarico	RAN	B	264	339	363	409	432	467	741	63	flat		3.0	flat
Tricarico	RAN							780				flat		4.69
Valle Aterno A	RAN	B	246	324	404	458	510	552	324	10	9.4			bb
Valle Aterno Aquilpark	RAN	B	510	558	614	629	677	717			0.6			0.5
Valle Aterno centro valle	RAN	B	337	403	458	488	485	474	515	48	2.5	3.1	3.0	2.4
Valle Aterno colle grilli	RAN	B	586	650	641	639	664	685	639	20		6.3		bb
Valle Aterno Pettino	RAN	A	500	593	693	758	802	830	500	7		1.9		flat
Varese Ligure	RAN	A	436	600				855	458	6		14.8	18	
Vibo Marina	RAN	B	290	290	329	379	417	450	465	34		5.2		5.2
Vibo Valentia	RAN	B	250	343	392	423	473	510	427	21		13.5		bb
Vieste	RAN	B	279	302	321	355	408	440	355	20	2.8		4.1	2.9

Balvano	UNIBAS	B	207	267	317	360	392	413			2.0
Bernalda Scuola	UNIBAS	B	410	429	408	394	390	383			0.6
Cagli Municipio	UNIBAS	E	218	308	394	470	530	580	343	12	3.4
Cagli Vigili del Fuoco	UNIBAS	E	168	200	238	280	323	360	280	20	4.2
Latronico scuola	UNIBAS	B	217	269	304	329	350	376			1.7
Marsico Nuovo	UNIBAS	B	325	335	336	359	382	399	439		2.5
Melfi	UNIBAS	B	232	301	348	376	408	434			2.4
Metaponto Borgo	UNIBAS	C	362	339	312	334	328	323			1.2
Offida Cappuccini	UNIBAS	B	297	321	338	380	422	455			1.0
Offida Municipio	UNIBAS	C	200	242	282	287	320	349	350		1.8
Offida Rocca	UNIBAS	B	239	248	280	320	353	378			1.5
Offida Stadio	UNIBAS	B	370	378	397	439	469	492	500		1.2
Passo di Treia	UNIBAS	B	263	357	419	463	498	525			3.4
Pisticci Cantisano	UNIBAS	B	270	311	355	376	410	399			0.6
Policoro Agrifela	UNIBAS	C	242	249	260	262	273	278			1.2
Policoro Municipio	UNIBAS	B	312	376	425	399	401	390			1.0
Potenza Campus	UNIBAS	E	312	483	705	722	722	725			4.3
Potenza Viale UNICEF	UNIBAS	B	212	336	418	468	529	580			2.0
S. Basilio-Scanzano	UNIBAS	C	262	266	270	278	285	292			1.4
Scanzano Ionico Municipio	UNIBAS	B	366	431	456	417	428	420			0.4
Tito Scalo	UNIBAS	D	95	123	141	155	166	175	199		1.2
Treia Carabinieri	UNIBAS	B	284	286	350	391	410	422			2.3
Venosa	UNIBAS	B	224	301	342	375	395	431	417		0.4
Villa d'Agri Barricelle	UNIBAS	B	222	287	328	359	384	408	400		3.5

2. Relevance for DPC and/or for the scientific community

This deliverable is of relevance for DPC and the scientific community since it explores the feasibility of new soil classification for the definition of the seismic action for design. Parameters alternative to $Vs_{,30}$, the parameter actually used in the Italian and European seismic norms, are invoked by the scientific community, as the effectiveness of $Vs_{,30}$ as the best estimator of the seismic response of a site is under debate since a decade (see Deliverable 12, this project).

3. Changes with respect to the original plans and reasons for it

No changes respect to the original plan were needed.

4. References

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5. Key publications/presentation

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Luzi L., Gallipoli M.R., Pacor F., Mucciarelli M., 2009. Caratterizzazione dei siti della banca dati ITACA per una nuova classificazione dei suoli. Abstract presented at the Conference of the Gruppo Nazionale Geofisica della Terra Solida, Trieste (Italy), 16 - 19 November 2009.

Luzi L., Gallipoli M.R., Pacor F., Mucciarelli M., 2009. Characterization of Italian strong-motion recording sites in the perspective of a new soil classification. Abstract presented at the DPC-INGV 2007-2009 General Meeting S-Projects, Roma 19-21 October

Pacor F, L Luzi, D Bindi, S Parolai, M Picozzi, M Pilz, M Mucciarelli, M Gallipoli, R Paolucci, 2009. Characterization of Italian strong-motion recording sites for a new soil classification, Abstract presented at Eos Trans. AGU, 90(52), Fall Meet. Suppl., Abstract S43A-1961.