A NEW SITE CLASSIFICATION FOR THE ITACA STATIONS BASED ON THE PREDOMINANT PERIOD OF H/V RESPONSE SPECTRA RATIO

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ABSTRACT

We propose a quick and inexpensive site classification method for stations of the Italian Accelerometric Network. Following the previous work by Di Alessandro et al. (2008 and 2009) we propose a site classification method based on the predominant period of ground motion at the site. The site predominant period is identified from the average horizontal-to-vertical (H/V) spectral ratios of the 5%-damped response spectra of Italian earthquake records. We have selected 602 three-component analogue and digital recordings from 120 earthquakes recorded at 214 seismic stations within an hypocentral distance of 200 km. Selected events are in the Mw range of 4.0 to 6.8 and the focal depth ranges from 5 to 40 km. Whenever possible, we classified each site by assigning them to one of six predominant period classes (in the range 0.05 to 2 seconds) that we propose as a modification of the Zhao et al. (2006) procedure. We then investigate the impact of this classification scheme on empirical ground-motion prediction equations (GMPEs). We adopted the same functional form of Fukushima et al. (2007) and we computed a nonlinear period- dependent regression that allowed us to derive site coefficients using the proposed six predominant period classes. Our empirical site classification scheme based on strong-motion data provides the opportunity to explore whether we can decrease the misfit by improving the site characterization of the Italian data set. Comparison of our results with GMPEs based on a conventional site classification provides only a small reduction of overall standard deviation. However, our scheme allows to recognize well distinguished behavior of the proposed classes, both in terms of predicted spectral shape and relative amplification with respect to rock sites. Furthermore, the small values of the standard error of the mean amplification (around 10%) give us confidence in the predictive capability of our approach. As a conclusion, the use of H/V spectral ratios in site classification results in promising highlights on capturing the signature of typically flat frequency-response sites as well as deep and shallow soil profiles, characterized by long- and short-period resonance, respectively, with the advantage of a relatively quick and inexpensive method. A comparison with the conventional classification based on Vs30 criteria indicates that our approach is able to distinguish sites with different spectral response that would be not distinguished in terms of Vs30. The tools we propose are especially useful in the recognition of rock sites to be used as reference stations, through the innovative classification criterion of a flat, unitary level in the H/V response spectra ratio.

1. DATA - SET

The selection of the strong-motion data has been operated among the available digital and analog uncorrected accelerograms of Italian earthquakes from 1972 to 2004, collected in the IT.AC.A (Italian Accelerometric Archive) data-base (http://itaca.mi.ingv.it). Additional accelerometric signals for selected recent (2005-2008) events with Mw > 4.0 were retrieved from the Rete Accelerometrica Nazionale (RAN) operated by the Dipartimento Protezione Civile.

After the removal of some stations that were suspected of having soil-structure interaction, signals were pre-processed to remove the baseline trend and were filtered with a Butterworth fourth-order acausal high-pass filter with a maximum cut-off frequency of 0.33Hz, in order to preserve information up to 2 seconds of spectral period.

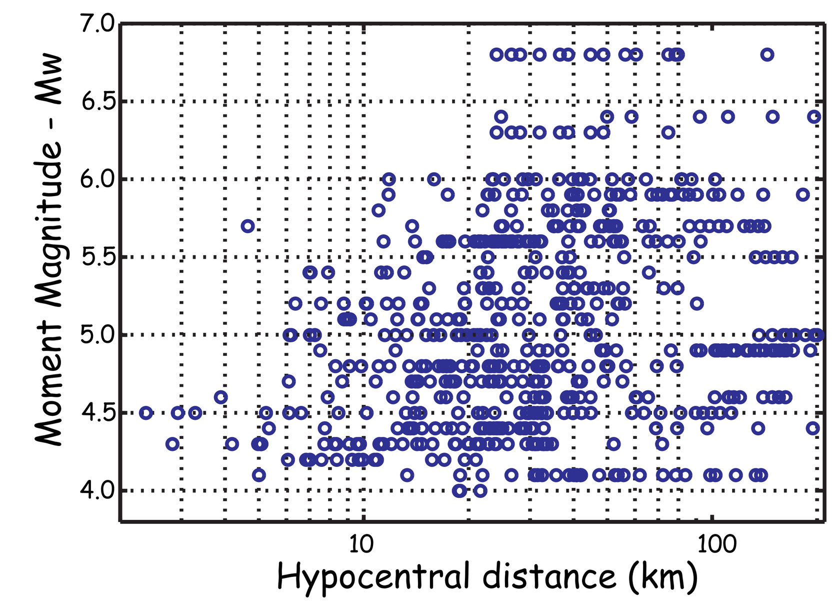
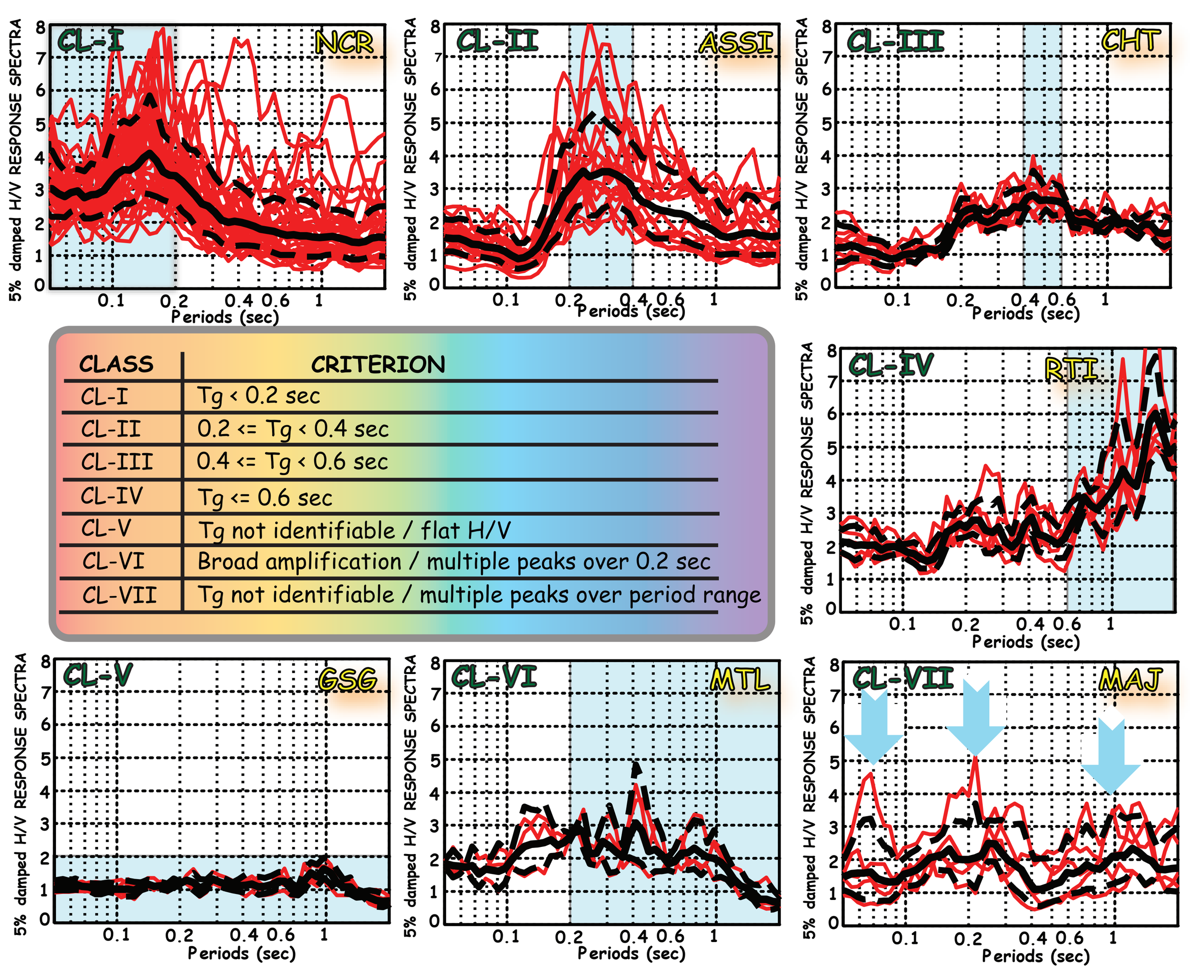


FIGURE 1: *the data-set consists of 602 three-component digital and analog recordings from 120 earthquakes recorded at 214 seismic stations within an hypocentral distance of 200 km. Moment-magnitude (Mw) range from 4.0 to 6.8. The largest events have focal depth in the range 5 to 40 km whereas smaller events can be shallower, up to few kilometres.*

2. CLASSIFICATION SCHEME

We modify Zhao et al. (2006) and Fukushima et al. (2007) classification criterion based on the predominant period of each station identified from the average H/V spectral ratio of the 5%-damped response spectra and we apply to the Italian data-set The classes are defined on the basis of the scheme in Fig. 2.



CLASS	CRITERION
CL-I	Tg < 0.2 sec
CL-II	0.2 <= Tg < 0.4 sec
CL-III	0.4 <= Tg < 0.6 sec
CL-IV	Tg <= 0.6 sec
CL-V	Tg not identifiable / flat H/V
CL-VI	Broad amplification / multiple peaks over 0.2 sec
CL-VII	Tg not identifiable / multiple peaks over period range

FIGURE 2: *proposed classification criterion based on the predominant period identified from the average H/V spectral ratio (black solid line) of the 5%-damped response spectra recorded at each site (red curves). The first four classes (CL-I to CL-IV) are defined using the same criterion of Zhao et al. (2006), according to the period band (blue area) where the predominant peak occurs. We introduce further three classes to take into account stations that could not be classified as a function of a unique peak. We classify a station as CL-V if it displays an almost flat average H/V response spectral ratio with no clear peak (< 2), whereas we classify it as CL-VI if there is a broad amplification at periods longer that 0.2 s or if there is more than one peak and all peaks occur at periods longer than 0.2 s (blue arrows point at multiple peaks). If multiple peaks take place both before and after the 0.2 s period threshold, the station is referred as "unclassifiable" (CL-VII).*

At the end of the analysis, we were able to classify 111 stations that recorded more than one event. We made an attempt of classification also for those stations displaying single events, considering the two horizontal components as independent, but we retained the information only for the regression computation.

3. GROUND MOTION PREDICTION ANALYSIS

In order to investigate the impact of the new site classification on predicted response spectra we performed a two-step nonlinear period-dependent regression that allowed us to derive site coefficients using the proposed predominant period classes. We also derived site coefficients for the simplified classification based on rock / soil distinction. The adopted functional form is:

$$LOG_{10}(Sa(T)) = a(T) + b(T)M + c(T)M^2 + d(T)(R) - \log_{10}(R + e(T)10^{f*M}) + S(T)\,j$$

Despite the relatively small reduction of standard deviation at shorter periods when we use classification based on predominant period (Fig. 3), our scheme allows to recognize well distinguished behavior of the proposed classes, both in terms of predicted spectral shape (Fig. 4) and relative amplification (Fig. 5a and 5b) with respect to rock site (i.e. AB and CL-V sites). The small values of the standard error of the mean amplification (around 10%) give us confidence in the predictive capability of our proposed approach.

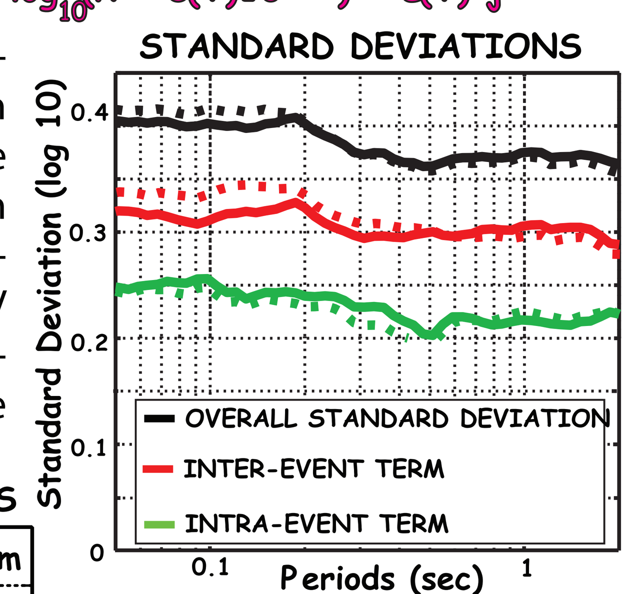


FIGURE 3: *overall, inter (red curves) and intra event (green curves) standard deviarion for our derived GMPE models based on predominant period (solid lines) classification and on simplified binary AB/CD (rock/soil) classification (dotted lines).*

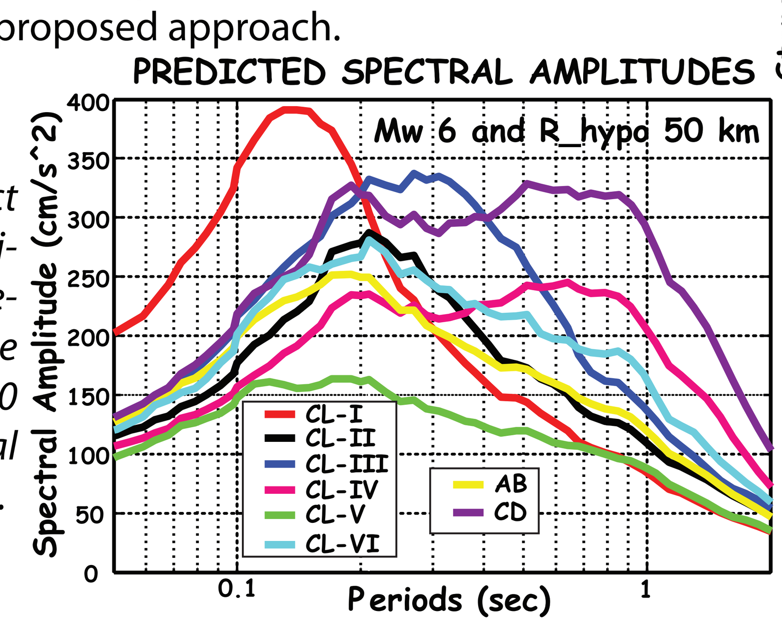


FIGURE 4: *effect of our site classification on predicted response spectra for Mw 6.0 and hypocentral distance of 50 km.*

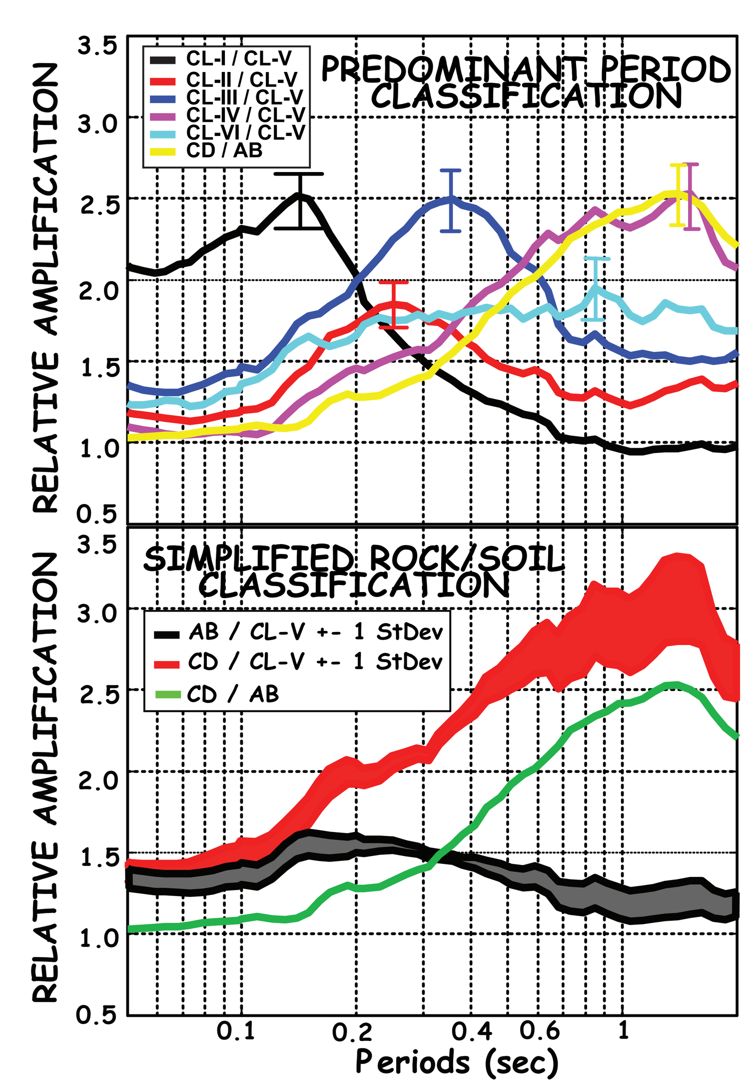


FIGURE 5a: *relative amplification of predominant period site classes with respect to class CL-V is shown, as well as of combined CD with respet to AB. The error bars are proportional to the SEM (Standard Error of the Mean) 0f the amplification.*

FIGURE 5b: *relative amplification of AB and CD sites with respect to CL-V were derived by averaging different scenarios commensurate in our dataset. Relative amplification of CD versus in AB is also shown for comparison.*

We also compared our predicted spectra with the ones for which the site classifications is based on conventional criteria, using compatible distance metrics (Fig. 6).

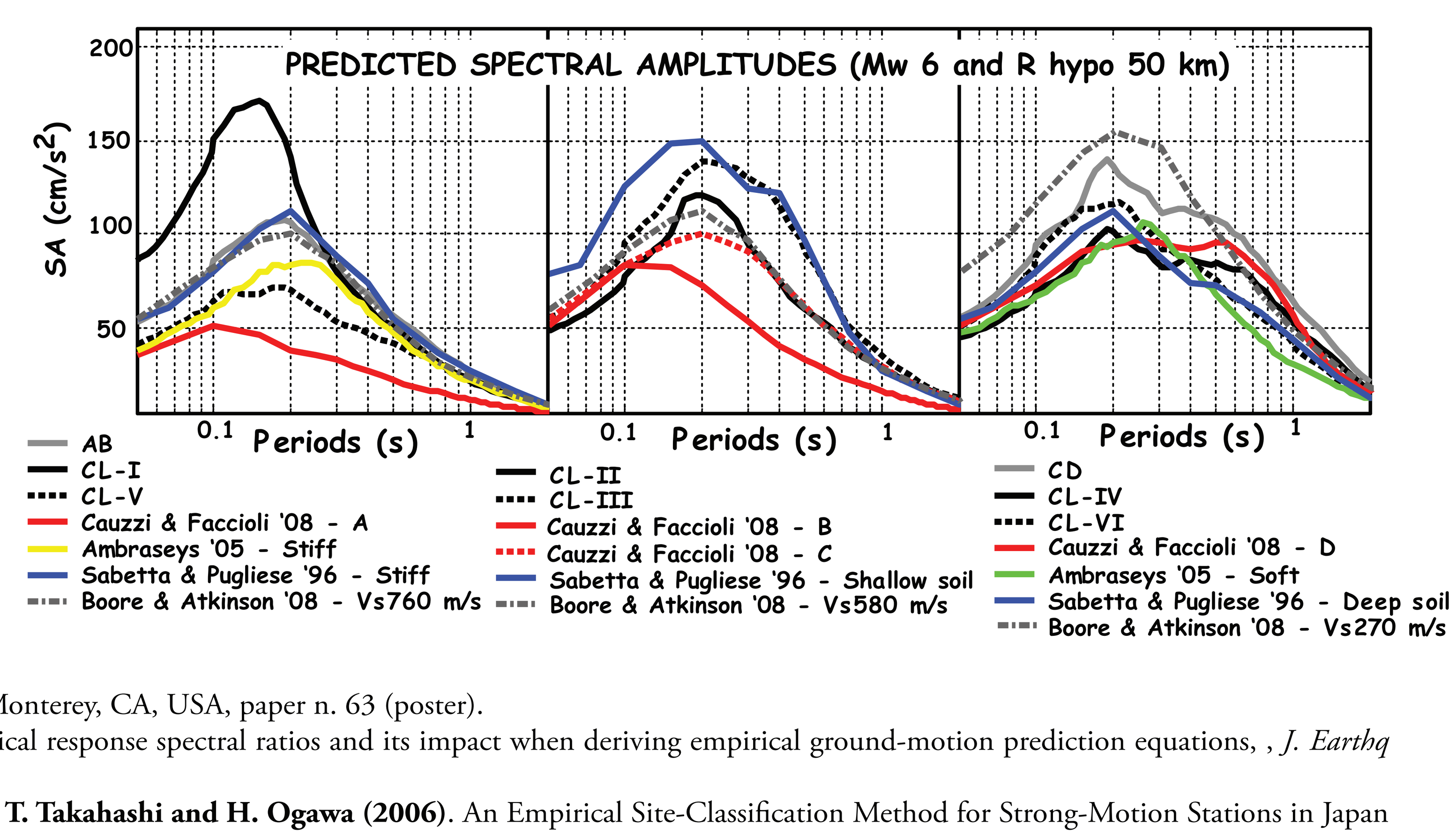
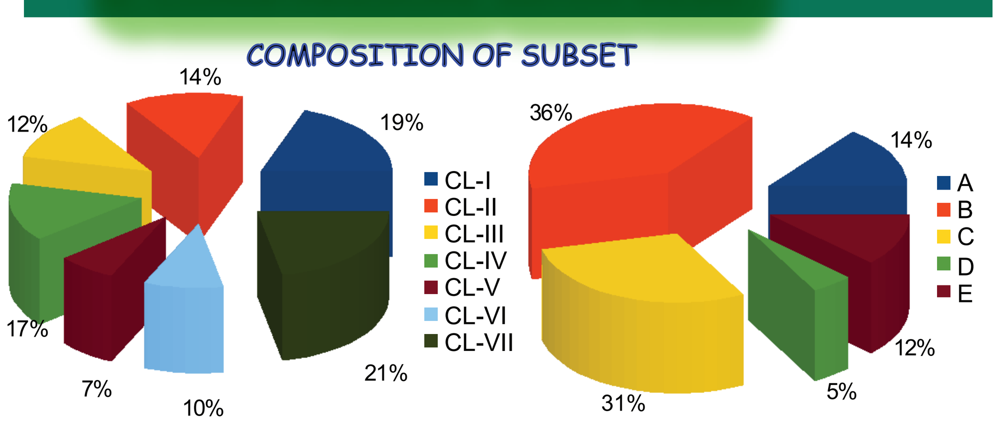


FIGURE 6: *comparison of predicted response spectra for Mw 6.0 and hypocentral distance 50 km for sites that amplifiy at short periods or have a rock -like behavior (left panel), for sites that amplify at intermediate periods or have a shallow-soil - like behavior (central panel) and for sites that amplify at long periods or have a deep-soil - like behavior (right panel).*

4. COMPARISON WITH Vs30



Additionally, we collected determinations of Vs30 (Eurocode EC8, CEN 2000) for 42 stations for which we also performed a classification based on predominant period from earthquake recordings. Vs determination came primarily from cross-hole and down-hole measurements, and secondarily from non invasive active and passive seismic experiments (ReMi and seismic refraction surveys). More than the 60% of this subset is composed of B and C sites.

FIGURE 7: *partitioning of sites with available Vs30 determinations into classes based on predominant period from earthquake recordings (left diagram) and on the Eurocode-8 site classification (right diagram).*

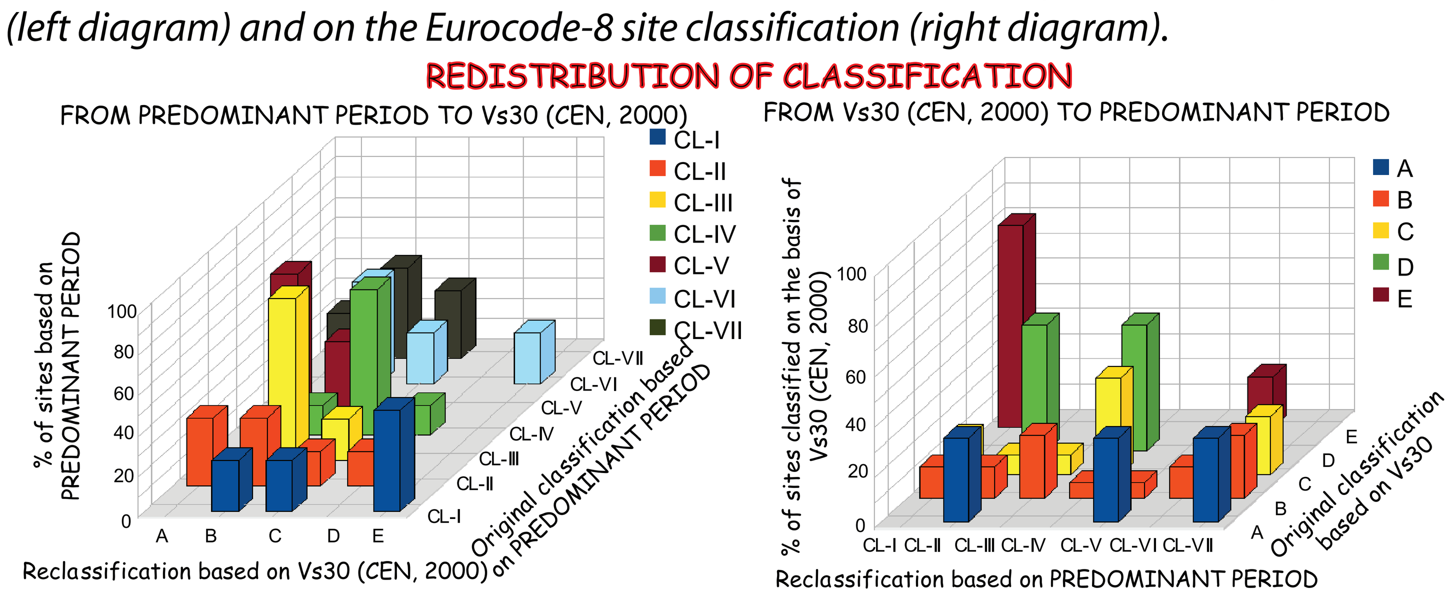


FIGURE 8: *comparison of site classes based on earthquake and noise recordings. The horizontal axis shows how sites classified according to earthquakes (left graph) and Vs30 (right graph) are reclassified.*

The comparison between classifications based on predominant periods of H/V and Vs30 shows that there is not a unique relation between Vs30 classes and period-defined classes. The one exception is CL-I and E, although E is not based on Vs30 but rather on presence of thin layer above hard rock or fractured rock. Furthermore, our classification scheme has the advantage that captures the physics of the wave propagation at the site better than the use of Vs30 alone.

ACKNOWLEDGMENTS

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REFERENCES

- **Di Alessandro, C., Bonilla, F., Rovelli, A. and O. Scotti (2008)**. Influence of site classification on computing empirical ground-motion prediction equations in Italy, AGU Fall Meeting, San Francisco, CA, USA, 15-19 December 2008, paper n. S12A-05.
- **Di Alessandro, C., Rovelli, A., Milana, G., Marcucci, S., Bonilla, F.L., and D.M. Boore (2009)**. A new site classification scheme for Italian accelerometric stations, in the 2009 SSA Annual Meeting, Monterey, CA, USA, paper n. 63 (poster).
- **Fukushima Y., Bonilla, F., Scotti O., Douglas J. (2007)**. Site classification using horizontal-to-vertical response spectral ratios and its impact when deriving empirical ground-motion prediction equations, , *J. Earthq Eng.*, 11, 712-724.
- **Zhao, J. X., K. Irikura, J. Zhang, Y. Fukushima, P. G. Somerville, A. Asano, Y. Ohno, T. Oouchi, T. Takahashi and H. Ogawa (2006)**. An Empirical Site-Classification Method for Strong-Motion Stations in Japan Using H/V Response Spectral Ratio, *Bull. Seism. Soc. Am.*, 96, 914-925.