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TESTING THE USE OF LOCAL SLOPE AS A PROXY OF GMPE'S SITE CONDITIONS

Boumédiène DERRAS[1], Pierre-Yves BARD[2], Fabrice COTTON[3] and Anne LEMOINE[4]

ABSTRACT

In the past few years it has been proposed to use the topographic slope from digital elevation models (DEMs) to give first-order estimates of NEHRP site classes based on the average shear-wave velocity in the top 30 m, V_{S30}. The direct testing of the correspondence between local slope and V_{S30} has already been evaluated with variable success on different data sets (e.g. Lemoine et al., 2012). Here, we take advantage of a recent high quality accelerometric database developed in Europe (References database for Seismic grOund-motion pRediction in Europe (RESORCE) to evaluate and analyse the relative decrease of the ground-motion aleatory variability brought by the consideration of V_{S30} and/or local slope as a proxy to site conditions. A subset of the RESORCE database consisting of shallow crustal events recorded on sites with actually measured V_{S30} values and available slopes (i.e., close to 1000 recordings for RESORCE) is considered. The Artificial Neural Network (ANN) approach and a random-effects like procedure have been used for the derivation of GMPEs setting the relationship between various ground motion parameters (PGA, PGV and 5% damped pseudo-spectral acceleration PSA from 0.01 s to 4 s), and event / station meta-parameters (moment magnitude M_w, Joyner- Boore distance R_{JB}, and site proxies V_{S30} and/or slope). This preliminary analysis shows the lower and rather poor performance of the local topographic slope in reducing the GMPE aleatory variability, compared to the performance of measured V_{S30}. The analysis is performed both using discrete site classes (mainly A/B, C and D, NEHRP notation) and continuous proxy values [$\log_{10}(V_{S30})$ and $\log_{10}$(slope)].

INTRODUCTION

It is widely common to account for local site effects by characterizing site conditions in terms of shear-wave velocity, V_S of the upper layers at the site. For example, the European seismic building code Eurocode 8 (EC8) is classifying soils conditions into four categories (D to A) by using the average V_S down to a depth of 30 m (V_{S30}) (Lemoine et al., 2012). It has been observed (e.g., Borcherdt, 1994) that V_{S30} is a useful parameter to predict local site amplification in active tectonic regimes but V_{S30} only cannot, of course, well predict the amplification for sites underlain by deep sediments, which require knowledge of the geology to depths greater than 30 m (e.g.,Choi et al., 2005). V_{S30} is a simple metric that can be obtained at relatively low cost compared to more detailed

[1] Associate professor, RISAM laboratory-Tlemcen University, Tlemcen, b_derras@mail.univ-tlemcen.dz
[2] Senior scientist, ISTerre, Univ. Grenoble Alpes/ IFSTTAR, Grenoble, pierre-yves.bard@ujf-grenoble.fr
[3] Professor, ISTerre-Univ. Grenoble Alpe, Grenoble, fabrice.cotton@ujf-grenoble.fr
[4] BRGM, Orléans, France

descriptions of site characteristics, and it is correlated with site amplification (Boore et al., 2011). Because of this simplicity, V_{s30} is widely used in seismic building codes. However, in many seismically active regions of the world, the information about surficial geology and shear wave velocity (V_S) either does not exist, varies dramatically in quality, varies spatially, or is not easily accessible. Topographic elevation data, on the other hand, are available at uniform sampling for the globe (Allen and Wald, 2009).

In the past few years a series of articles have been published concerning the use of topographic slope from digital elevation models (DEMs) constructed through remote sensing (satellite imaging) to give a first-order estimation of site classes based on V_{S30} (Wald and Allen, 2007, Allen and Wald, 2009).

Does this rather simple parameter give first-order site amplification information? Are slope based amplification similar to amplification factors based on V_{s30}? The aim of this work is to evaluate and analyse the relative decrease of the ground-motion aleatory variability brought by the consideration of V_{S30} and/or local slope as a proxy to site conditions. This analysis is performed by interpreting results obtained from ground motion prediction equations (GMPEs). The analysis is performed both using discrete site classes (mainly B and C, EC8 notation) and continuous proxy values [$\log_{10}(V_{S30})$ and $\log_{10}$(slope)].

The used database, RESORCE, consists of shallow crustal events recorded on sites with actually measured V_{S30} values and available slopes (Akkar et al., 2014). The Artificial Neural Network (ANN) approach and a random-effects like (Derras et al., 2014) procedure have been used for the derivation of GMPEs setting the relationship between various ground motion parameters (PGA, PGV and 5% damped pseudo-spectral acceleration PSA from 0.01 s to 4 s), and event / station meta-parameters (moment magnitude M_w, Joyner- Boore distance R_{JB}, and site proxies V_{S30} and/or slope).

After a short presentation of the data set and the selection criteria used for the present study, a section is dedicated to the presentation of the ANN models and its specific implementation in the present application. The following section concentrates on the results of the application to the RESORCE data. The ANN has the advantage that no prior functional form is needed (Derras et al., 2012): the actual dependence is established directly from the data, and can therefore be used as a guide for a better understanding of the factors which control ground-motions. The ANN approach is used to discuss the respective influences of each considered site proxy.

DATA SET

The strong motion data set is based on the RESORCE European database. It consists of a subset for which both site proxies, i.e., V_{S30} and slope, are available. We have eliminated all the recordings for which M_w is unavailable and recordings from events with a depth larger than 25 km, to focus on shallow crustal earthquakes. Only sites with measured V_{S30} values have been considered. Such selection criteria result in a total of 1028 recordings, covering the magnitude range [3.6–7.6] and a Joyner & Boore distance (R_{JB}) range [1 – 200] km. The V_{s30} values are in the range [92 - 1600] m/sec, while the corresponding topographic slopes are in the range [5.10^{-4} - 0.32] m/m. It turns out that most of the recordings come from Turkey (624) and Italy (359). The data from the two countries do not cover the same magnitude and distance range. Derras et al. (2014) indicates that the majority of Turkish earthquakes are recorded at a distance larger than 30 km (unlike Italy) and cover a larger magnitude range than Italian earthquakes.

The distribution of this dataset according to M_w, distance, and site proxy planes is displayed on Figures 1 and 2. In this last figure, we are also representing the values of site classes intervals in terms of V_{S30} values (m/sec) and topographic slope (m/m) for the EC8 classification (A, B, C and D) with the membership in (%) for each class ($V_{s30} \cap$Slope). From this figure we note that there are no recordings corresponding to soft sites (class D), while class A data represent less than 2% of the total database, knowing also that the neural model is driven by data, the models developed in this study will not be valid for Class A.

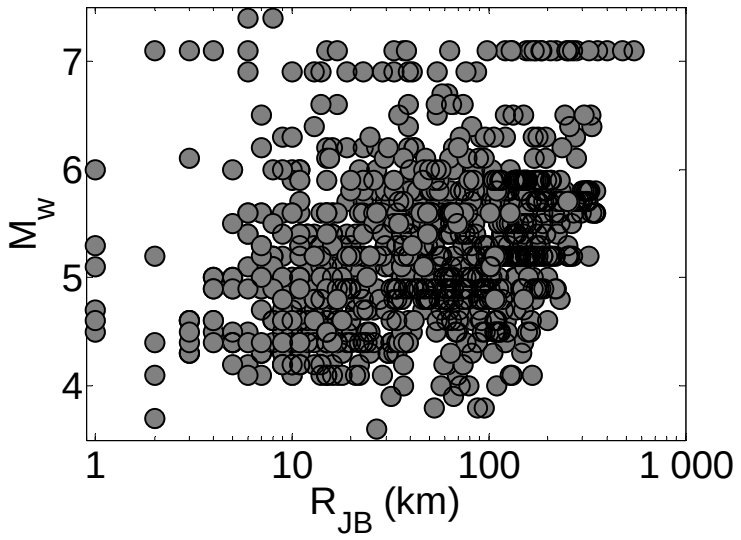


Figure 1. Distribution of the data set. Magnitude M_w vs distance (R_{JB})

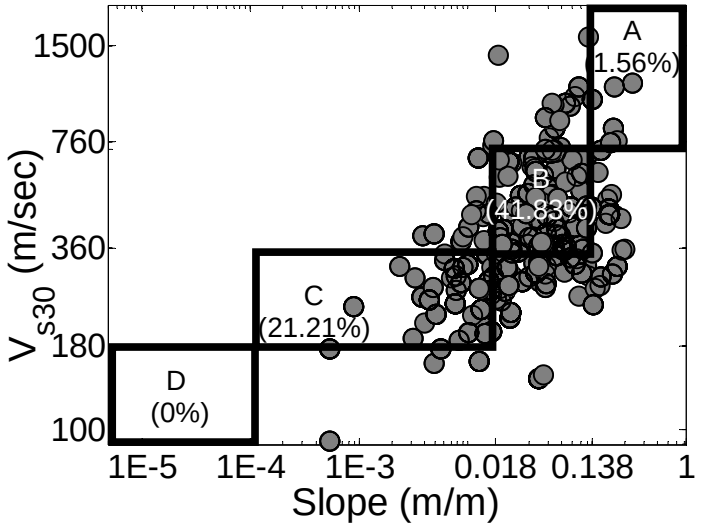


Figure 2. Correlations of measured V_{S30} (m/sec) versus topographic slope (m/m). Boxes represent V_{S30} and slope ranges recommended by Wald and Allen (2007) and Allen and Wald (2009) for active tectonic areas for classification into NEHRP categories (roughly equivalent to EC8 classes (Lemoine et al., 2012)).

ANN MODELS

The Artificial Neural Network Model of Multilayer Perceptron with a total connection is used here, with one hidden layer (Figure 3). The ANN type used in this work is the feed-forward ANN. The Quasi-Newton Back Propagation technique also called “BFGS” has been applied for the training phase (Shanno and Kettler, 1970). To avoid “over-fitting” problem we chose the adequate regularization method (Derras et al., 2012). Moreover, the selected activation functions are a "tangent sigmoïd" for the hidden layer and "linear" for the output layer. In figure 3, the symbols *W* and b represent the synaptic weights and bias with subscripts representing the corresponding neurons between two layers, respectively. The hidden layer consists of 3-neurons and the output layer groups all the considered ground motion parameters, i.e. peak ground velocity (PGV), peak ground acceleration (PGA), and 5%-damped pseudo-spectral acceleration (PSA) at 62 periods from 0.01 to 4 s. A procedure similar to the random-effects approach was used to provide between- and within-event standard deviations, as described in Derras et al., (2014). Four different ANN models were built, differing by the site proxy used in the input layer. Besides the moment magnitude M_w, and $\log_{10}(R_{JB})$ where R_{JB} is the Joyner &

Boore distance, the site proxies are the site classes derived from a. V_{S30} (EC8 classes B and C, i.e., V_{S30} within the range [360 – 800 m/s] and [180-360 m/s]), b. the corresponding slope range as proposed by Wald & Allen (2007), as displayed in Figure 3-left. C. continuous site proxy, i.e., $\log_{10}(V_{S30})$ or $\log_{10}$(slope), as displayed in Figure 3-right. In addition, a fifth ANN model was considered with only two input parameters (magnitude and distance) and no site proxy, in order to set the reference for quantifying the gains brought by the consideration of the various site proxies.

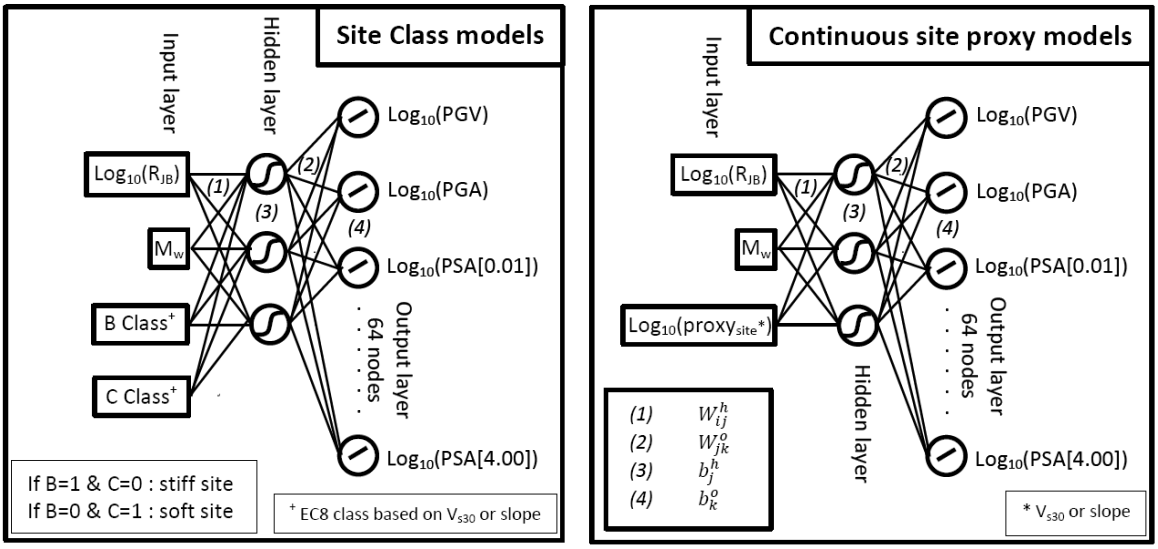


Figure 3. Structure of the Neural Networks considered in this study, for discrete (left) and continuous (right) site proxies

RESULTS

The five models are named ANN-V_{s30}-C and ANN-slope-C for discontinuous models (figure.3 left) and ANN-V_{s30} and ANN-slope for continuous models (figure.3 right). The fifth ANN model (without any site proxy) is named ANN-none.

The ANN model is obtained using the random-effect model (Abrahamson and Youngs, 1992). In addition to the median, this approach gives the aleatory uncertainly model. The performances of the results obtained by ANN are measured by the standard deviation σ value used in classical GMPEs.

Sigma (σ) is usually decomposed into the between-event (τ) and within-event (ϕ) variabilities, which are zero-mean, independent, normally distributed random variables with standard deviations τ and ϕ, (Al Atik et al., 2010). The between-events and within-event residuals are uncorrelated, so the total standard deviation σ at a period T of the ground-motion model, σ, can be written as:

$$\sigma(T) = \sqrt{\tau(T)^2 + \phi(T)^2} \qquad (1)$$

The variations of τ, ϕ and σ versus the period are presented on Figure 4 for the five ANN models. The values of the between-event variability τ are much lower than the within-event variability ϕ values. These values exhibit a general trend of an increasing variability with period (figure 4). In the other hand, all ANN models depict almost the same variability for periods lower than 0.5 sec (figure 4).

The relevancy of the site proxy is evaluated by its ability to reduce the residuals between predictions and observations (i.e., the aleatory variability σ). For T>0.5 sec (Figure 4), the σ reduction shown by models using site proxies is clear. It turns out that the smallest reductions correspond to the cases where the site proxy is the slope, used either for site classification (ANN-slope-C) or as a

continuous site parameter (ANN-slope), while the largest reductions are obtained with measured V_{S30} as input. These reductions are very clear for periods above 0.5 sec for within-event variability.

In addition, we represent the values of σ and the variance reduction coefficient R Eq.(2) in Table 1 for PGA and PSA at T=0.5, 1.0 and 2.0 sec. The obtained results confirm that the reduction becomes significant beyond T = 0.5 sec and for ANN-V_{s30} and takes its maximum at T = 1.0 sec, R = 10 %.

$$R(T) = \left(\frac{\sigma(T)_{proxy}}{\sigma(T)_{none}} - 1\right).100\,;\ (\%) \qquad (2)$$

Otherwise, the distinction between between-event and within-event variabilities indicates that the aleatory reduction associated to the use of site proxies comes primarily from the reduction in the within-event variability, as expected

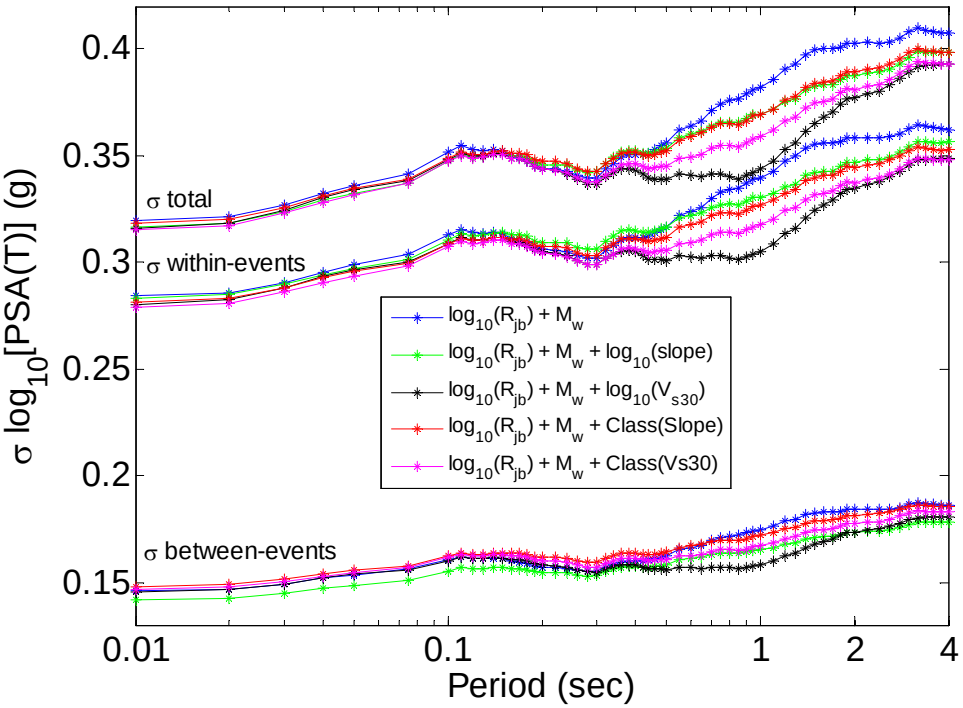


Figure 4: Sensitivity of the aleatory variability to the site proxy used as input for the neural network. Top left : total sigma as a function of period. Bottom left : between-event sigma. Bottom right: within-event sigma

Tabe 1. Total sigma (σ) and variation reduction (R) for the five ANN types and for T=0,5, 1 and 2 sec

ANN type	PSA σ and R(%)							
	T=0.00 sec		T=0.50 sec		T=1.00 sec		T=2.00 sec	
ANN-none	0.319		0.356		0.382		0.403	
ANN-slope-C	0.318	-0.3	0.353	-0.8	0.369	-3.4	0.389	-3.5
ANN-slope	0.316	-0.9	0.353	-0.8	0.370	-3.1	0.388	-3.7
ANN-Vs30-C	0.315	-1.3	0.345	-3.1	0.359	-6.0	0.381	-5.5
ANN-Vs30	0.314	-1.6	0.339	-4.8	0.344	-9.9	0.377	-6.5

As a complementary information to the effects of the input parameters on σ (table 1 and figure 4), and in order to illustrate the meaning of the internal synaptic weights of the ANN approach, the total percentage of synaptic weights P corresponding to each of the five parameters was computed (following the Eq.(4) indicated in Derras et al. (2014)).

These coefficients P have been computed for all ANN models shown in figure 5. According to the analysis of the internal synaptic weights, the most important parameter is the distance, followed directly by the earthquake magnitude, M_w. For site conditions, the internal synaptic weights associated to the measured V_{s30} is larger (P_{Vs30} =12 %) that the internal synaptic weights associated to the slope (P_{slope} = 9 %). This ranking is similar to the ranging obtained from the analysis of aleatory variabilities discussed above.

Figure 6 displays the magnitude and distance dependences of PGA and spectral accelerations at 0.2 s and 1.0 s. Besides the good performance of the ANN approach to account for the near-field saturation and magnitude-dependence of the spatial decay, a striking feature of these comparisons is the much smaller variations of predicted ground-motions according to site conditions when the slope is used as a site proxy (compared to the V_{S30} case) especially for small periods.

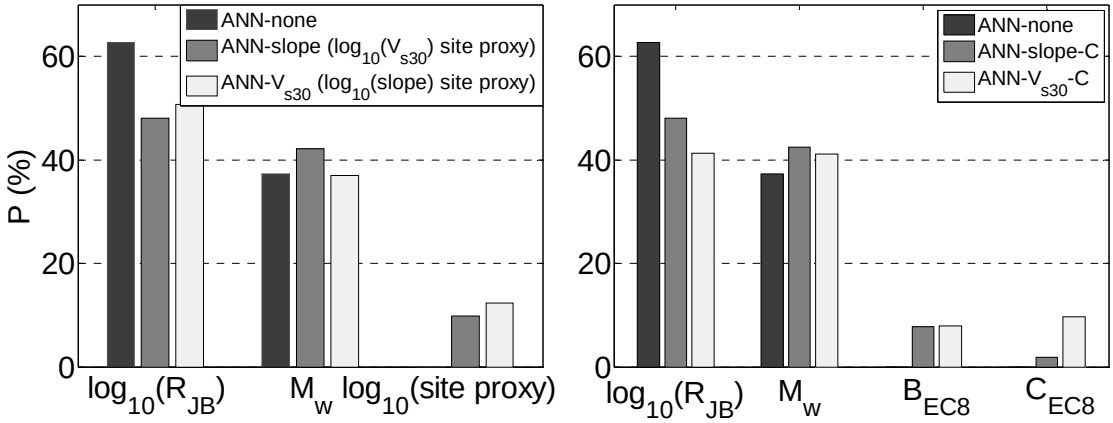


Figure 5. Sensitivity of the ground motion parameters to the metadata parameters, P (%) is the total percentage of synaptic weight corresponding to each input parameters for the cases of continuous (left) and discrete (right) site proxies.

CONCLUSION

This study investigated the impact of various site conditions proxies on ground-motions predictions models for a subset of the RESORCE data base involving 1028 recordings ranging from 3.6 to 7.6 in moment magnitude and from 1 to 200 km in Joyner&Boore distance, all with measured V_{S30} values

- The ground-motion aleatory variability σ associated to the derived GMPEs is minimum when using a site classification (i.e., EC8 site classes A, B and C) based on measured V_{s30}. Using slope values for assigning site classes is significantly less efficient in reducing σ.

- The same conclusion stands also for continuous models, with an even larger difference between V_{S30} based models and slope proxies based models.

For the considered data set, the reduction of the aleatory variability is effective in the intermediate to long period range, i.e. from 0.5 to 4 s, with maximum effects around 1.0 s period. It is worth to notice that larger variance reductions are associated with larger site factors (Figure 6). As a consequence, ground-motion models based on the slope proxy results in a much smaller differentiation of spectral amplitudes between soft and very stiff sites. This may lead to an underestimation of ground-motions.

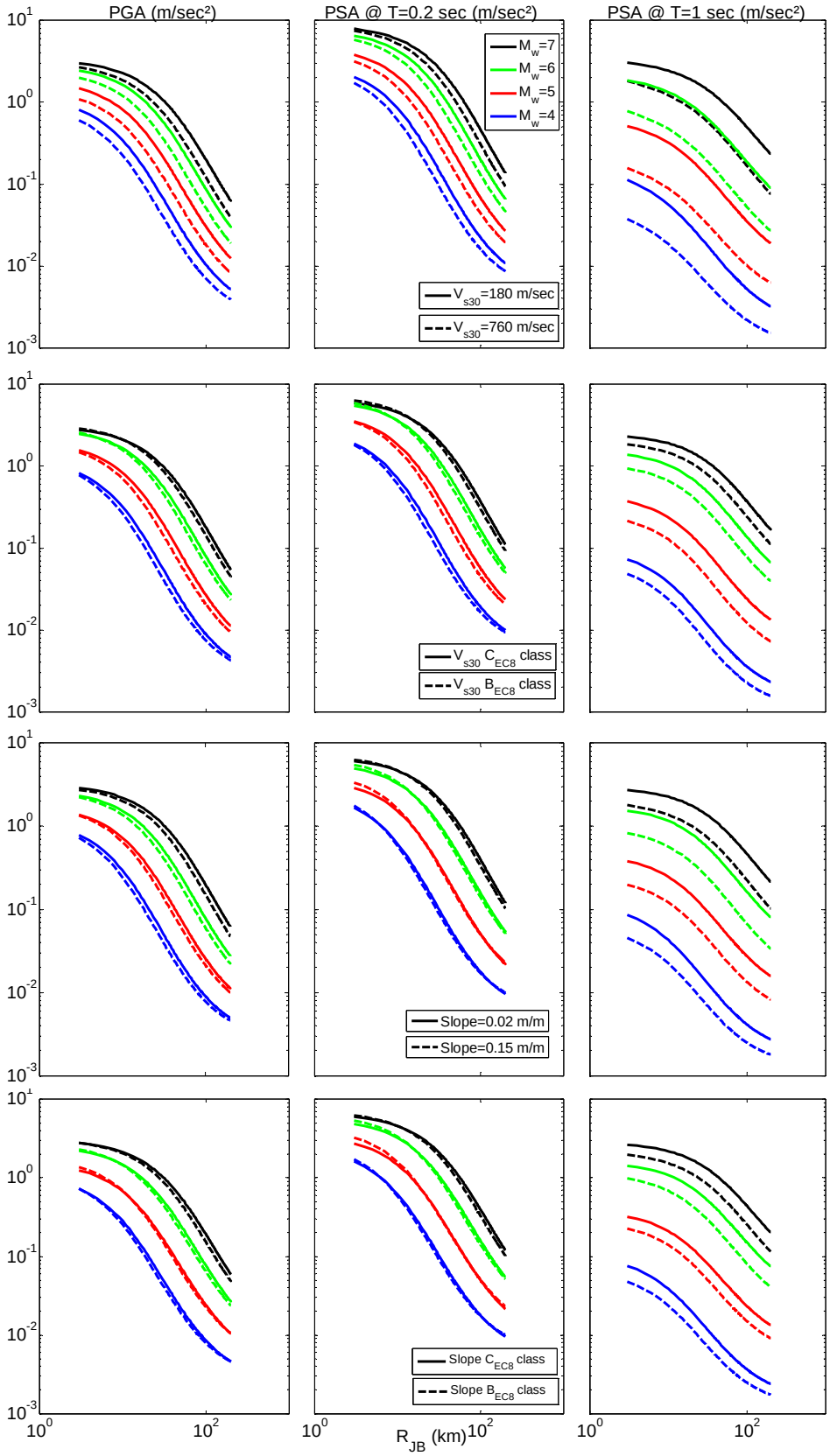


Figure 6. Magnitude and distance dependences of the predicted ground motions predicted by the four derived ANN ground-motion models .The three columns from left to right correspond to PGA, PSA(0.2 s) and PSA(1.0 s), respectively. The four rows correspond to the four ANN ground-motion models: $\log_{10}(V_{S30})$, $\log_{10}$(slope), Class(V_{S30}) and Class(slope), from top to bottom. In each case, the dashed line corresponds to a stiff site, and the solid line to a soft site.

DATA AND RESOURCES

The RESORCE database used in this article have been collected and disseminated by the Euro-Mediterranean Seismological Centre (EMSC) data management center at http://jaguar.emsc-csem.org/sigma/.

REFERENCES

Abrahamson NA and Youngs, RR (1992)" A stable algorithm for regression analyses using the random-effects model," *Bull Seismol Soc Am*, 82:505–510

Akkar S, Sandıkkaya MA, Senyurt M, Sisi AA, Ay BÖ (2014) "Reference Database for Seismic Ground-Motion in Europe (RESORCE)," *Bull. Earthq. Engng*, 12(1):311-339

Al Atik L, Abrahamson N, Bommer JJ, Scherbaum F, Cotton F, Kuehn N (2010)" The variability of groundmotion prediction models and its components," *Seismol Res Lett,* 81(5):794–801

Allen TI and Wald, DJ (2009)" On the use of high-resolution topographic data as a proxy for seismic site conditions (V_{S30})," *Bull. eismol. Soc. Am*, 99(2A):935‐943

Boore DM, Thompson EM, Cadet H (2011)" Regional Correlations of V_{S30} and Velocities Averaged Over Depths Less Than and Greater Than 30 Meters," *Bull. eismol. Soc. Am*, 101(6):3046‐3059

Borcherdt, RD (1994)" Estimates of site-dependent response spectra for design (methodology and justification)," *Earthquake Spectra,* 10(4):617‐653

Choi YJ, Stewart JP, Graves RW (2005)" Empirical model for basin effects accounts for basin depth and source location," *Bull. eismol. Soc. Am*, 95 (4):1412‐1427

Derras B, Bard P-Y, Cotton F (2014)" Towards fully data-driven ground-motion prediction models for Europe," *Bull. Earthq. Engng*, 12(1):495-516

Derras B, Bard P-Y, Cotton F, Bekkouche B (2012)" Adapting the neural network approach to PGA prediction:an example based on the KiK-net data," *Bull Seism Soc Am*, 102(4):1446–1461.

Douglas J, Akkar, A Ameri G, Bard P-Y, Bindi D, Bommer JJ, Bora SS, Cotton F, Derras B, Hermkes M, Kuehn NM, Luzi L, Massa M, Pacor F, Riggelsen C, Sandıkkaya MA, Scherbaum F, Stafford PJ, Traversa P (2014)"Comparisons among the five ground-motion models developed using RESORCE for the prediction of response spectral accelerations due to earthquakes in Europe and the Middle East," *Bull. Earthq. Engng*,12(1):341-358

Lemoine A, Douglas J, Cotton F (2012)" Testing the Applicability of Correlations between Topographic Slope and V_{S30} for Europe," *Bull. Seism Soc. Am*, 102(6): 2585-2599

Shanno DF and Kettler, PC (1970)" Optimal Conditioning of Quasi-Newton Methods," *Math. Comp*. 24(111): 657-664

Wald DJ and Allen, TI (2007)" Topographic slope as a proxy for seismic site conditions and amplifications," *Bull. Seism Soc. Am*, 97(5): 1379-1395