Short manual for training and use the ANN

1. ANN architecture

The deep ANN architecture consists of seven input branches (Figure 1). The first three correspond to the as recorded long-period spectral accelerations of the two horizontal components and the vertical component. The fourth branch includes scalar source and path parameters. Finally, the last three branches include EC8 site class (SC: A, B, C, or D), faulting mechanism (FM: normal - NF, reverse/thrust - TF or strike-slip - SS), and region (RG: Italy - IT, California - CA, Taiwan - TW, Türkiye - TR, Japan – JP, or Other – OT), respectively. These three branches are represented by a one-hot encoded vector, that for instance, it would be [1,0,0,0] for SC A, [0,0,1] for strike-slip FM, and [0,0,0,1,0,0] for Türkiye. Each input branch is first processed independently through fully connected layers, with hyperbolic tangent (tanh) activation functions for the first four layers, and rectified linear unit (ReLU) activation functions for the last three. Afterwards, they are merged via a concatenation layer, which is then passed to a fully connected hidden layer (common layer) with a tanh activation function. Processing these input groups through separate branches allows the network to learn distinct representations for spectral shape, scalar source–path effects, and categorical metadata before combining them, which improves training stability and interpretability compared to a single fully connected input layer.

Finally, this common layer connects to three separate output layers with linear activation functions, each predicting the short-period spectral accelerations of horizontal and vertical components. To ensure comparability across variables, z-score normalization is applied to the first four input branches. Input and output spectral accelerations are given in logarithmic scale ln(SA), with SA in m/s2. For each component we use a total of 29 SAs for periods going from 0 to 5 sec. These 29 periods are divided into input/output depending on the corner period T*. For instance, for T*=1 s, the output periods are [0,0.05,0.07,(0.1:0.05:0.5),0.6,0.7,0.75,0.8,0.9 s]. Distances are given in kilometers. The architecture of the ANN is defined inside the code **ANN_architecture.m**.

2. Training

For training the ANNs you have to run the code drive.m. Inside change the following options:

- dbn_name = 'ESM_NGA_130'; Name of the database with the spectral accelerations and metadata for training. It should be located inside the subfolder database.
- TransferLearning = 'False'; Use 'True' if you want to do a two-step training with transfer learning. In that case you need to define also dbn_name2, which is the database for the second training (fine tuning), otherwise dbn_name2 is ignored.
- dbn_name2; If TransferLearning = 'False' use the same name as in dbn_name.
- num_nets = 1; No. of individual nets trained with the same architecture and parameters.
- n_LoopsANN = 1; Number of trained nets before choosing the best one. (internal loop).
- add_distance = 'True'; 'True' to add R_{JB} as input for training in the fourth branch.
- add_m = 'True'; 'True' to add M_W as input for training in the fourth branch.

- add_lndistance ='True'; 'True' to add log(R_{JB}) as input for training in the fourth branch.
- add_vs30 = 'False'; 'True' to add log(Vs_{30}) as input for training in the fourth branch.
- add_depth = 'True'; 'True' to add hypo depth as input for training in the fourth branch.
- separate_classes = 'True'; for activating the fourth branch of the ANN, i.e., EC8 site classes.
- add_fm = ' True '; for activating the fifth branch of the ANN, i.e., focal mechanism.
- separate_regions = 'True'; for activating the sixth branch of the ANN, i.e., tectonic region.
- ann.trn.nr = 1; Number of ANNs to be trained with the same previous input options but different T* or component defined below.
- TnC = [1]; Corner periods T* of the ANNs.
- cp = {'h12v'}; Components (ud=vertical; h=horizontal rotational-invariant; or h12v= three components simultaneously, as in Figure 1).
- nnr = 1; %scaling factor to define number of neurons (see Figure 1): N1=nnr*No. input periods, N2=3*nnr*No. output periods
- vTn; Vector with the periods at which the spectral accelerations of the database are computed. It should at least include these 29 periods: [0,0.05,0.07, (0.1:0.05:0.5), 0.6,0.7, 0.75,0.8,0.9,1.0:0.2:2.0,(2.5:0.5:5)], which are separated in input/output according to T*.

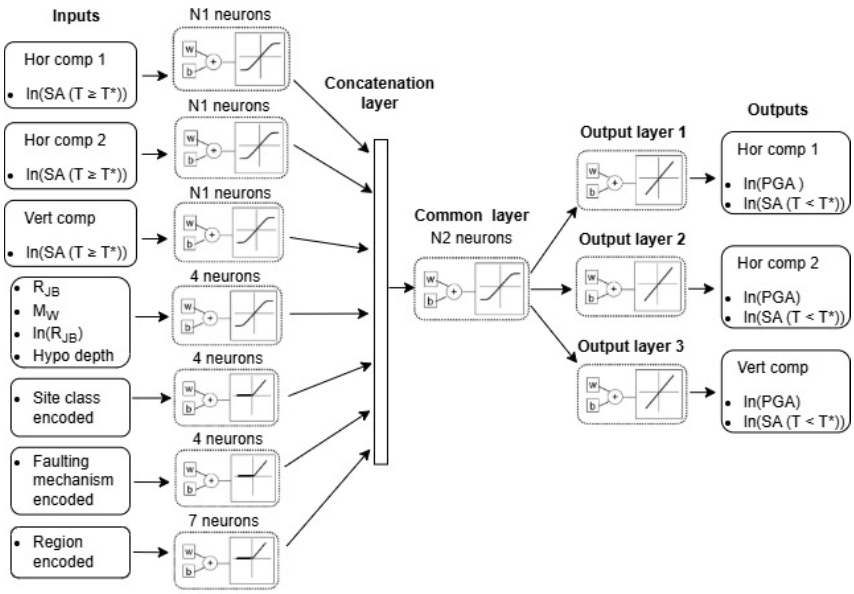

Figure 1. Architecture of the ANN.

3. Database

The database(s) for training should be inside the subfolder *database*. As a minimum it should contain spectral accelerations for the three components (fields psa_h1, psa_h2, and psa_v) in cm/s^2 (because internally a conversion to m/s^2 is done).

To use the codes without modifications, the database should be a Matlab structure named DATABASE, with these variable names (if used): Mw, Vs30, event_depth (hypocentral depth), fm_type (focal mechanism), site_EC8 (site class), area (tectonic region) and Rjb (in km).

The training is done in code train_ann_PSA.m. Up to line 775 what is done is basically preparing the training/validation/test input/target sets in the format needed by trainnet function.

DATABASE

1x5148 struct with 27 fields

Fields	Mw			Rjb	Vs30	area			event_depth			event_name	fm_type				psa_h1	psa_h2	psa_v		site_EC8	station_code
1	6.7000	3...	3...	24.0877	463.1899	"TR"	'A'	1...	6	4...	4...	"AM-1988-0001"	"TF"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	1	"C"	"GUK"
2	5.4000	2...	3...	18.5311	313.9050	"GE"	'A'	1...	28.3000	4...	4...	"AM-1990-0013"	"SS"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	2	"A"	"SAKH"
3	5.4000	1...	3...	13.2984	462.3633	"GE"	'A'	1...	28.3000	4...	4...	"AM-1990-0013"	"SS"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	3	"B"	"SBGD"
4	5.4000	4...	5...	42.4224	960.4749	"GE"	'A'	1...	28.3000	4...	4...	"AM-1990-0013"	"SS"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	4	"C"	"SBKR"
5	5.4000	7...	8...	74.1916	652.7728	"TR"	'A'	1...	28.3000	4...	4...	"AM-1990-0013"	"SS"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	5	"A"	"SPIK"
6	5.4000	9...	9...	88.4776	612.8986	"TR"	'A'	1...	28.3000	4...	4...	"AM-1990-0013"	"SS"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	6	"B"	"SVNZ"
7	5.2500	5...	5...	56.9000	543.4985	"TR"	'IU'	1...	15.6687	3...	3...	"EMSC-20050730_00...	"SS"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	9	"B"	"ANTO"
8	5.0800	8...	8...	86.8000	925.1307	"GR"	'...	1...	16.9101	3...	2...	"EMSC-20101003_00...	"NF"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	13	"A"	"KARP"
9	5.1000	1...	1...	125.3000	925.1307	"GR"	'...	1...	17.1669	3...	2...	"EMSC-20110508_00...	"NF"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	16	"A"	"KARP"
10	5.1000	7...	7...	77.9000	527.0462	"TR"	'K...	1...	17.1669	3...	2...	"EMSC-20110508_00...	"NF"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	17	"B"	"DIDI"
11	5.1000	5...	5...	50.2000	679.6280	"TR"	'K...	1...	17.1669	3...	2...	"EMSC-20110508_00...	"NF"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	19	"B"	"YKAV"
12	5.2400	7...	7...	71.9000	428.3132	"GR"	'...	1...	18.2442	3...	2...	"EMSC-20110519_00...	"SS"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	21	"B"	"GVD"
13	5.2400	1...	1...	129.6000	268.1635	"GR"	'...	1...	18.2442	3...	2...	"EMSC-20110519_00...	"SS"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	22	"C"	"SIVA"
14	5.0900	8...	8...	86.5000	793.0950	"TR"	'K...	1...	12.2162	4...	2...	"EMSC-20110725_00...	"NF"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	27	"B"	"GONE"
15	5.1900	6...	6...	65.7000	428.3132	"GR"	'...	1...	22.9116	3...	2...	"EMSC-20110913_00...	"SS"	[...	[...	[...	37x1 do...	37x1 do...	37x1 do...	29	"B"	"GVD"

Figure 2. Format of the Matlab structure with the data used for training.

We include file ESM_NGA_130.mat with the training dataset used in the paper, which combines records from earthquakes with Mw ≥ 5 and R_{JB} ≤ 130 km from the ESM database (Luzi et al., 2016), together with records from earthquakes with Mw ≥ 6.5 from the NGA-West2 database(Ancheta et al., 2014). The combination of ESM and NGA-West2 data was adopted to ensure adequate coverage of both moderate-to-large magnitudes and near-fault distances, while maintaining sufficient diversity in tectonic setting, site conditions, and source characteristics to support robust ANN training. The combined dataset consists of a total of 5148 three-component strong-motion records from crustal earthquakes with hypocentral depths less than 30 km. Figure 3 shows the M_w vs R_{JB} distribution of the records used for training the model.

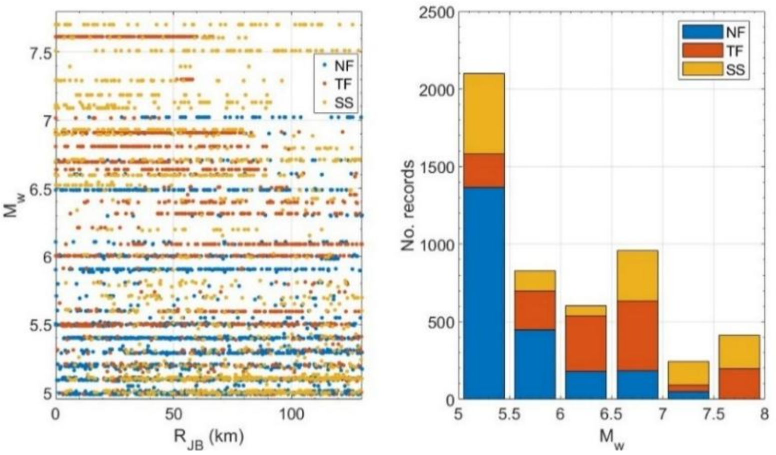

Figure 3. Magnitude vs distance R_{JB} scatter plot of recordings in the ESM+NGA data set used for training the ANN (left). Histogram of the number of events per magnitude bin (right).

4. Making predictions

The trained net with the inputs/targets divided in training/validation/test (trn/vld/tst) sets are stored in the structure NNs. The predictions from the ANN are saved in the field out_trn. The structure *NNs* is saved in the folder *ANNs*, with name having the following format:

net_(100*Tnc)_(cp)_(extra input variables)_(dbn_name)_v##

For instance, for the set of selected options shown in section 2, the name of the file would be:

net_100_h12v_Rjb_Mw_logRjb_Dh_Site_SoF_Reg_ESM_NGA_130_v01

You can make predictions with the Matlab function *predict*:

[out_h1,out_h2,out_v] = **predict**(NNs.net,in_h1,in_h2,in_v,branch4,branch5,branch6,branch7);

Where in_h1, in_h2, in_v are arrays with long-period spectral accelerations for each component. They should be given as ln(SA), with SA in m/s^2. For instance, for T*=1 s, there should be 12 input SA, at periods [1.0:0.2:2.0,(2.5:0.5:5)]. The predictions will be given for these periods [0,0.05,0.07, (0.1:0.05:0.5), 0.6,0.7, 0.75,0.8,0.9]. More than one prediction can be obtained at the same time, in such case the inputs and outputs are given as rows of the arrays. Branch4 should have these three columns [R_{JB},M_w,ln(R_{JB}),Vs30,Depth]. R_{JB} should be limited to values larger than 0.01 km. For branches 5, 6, and 7 the inputs are given in one-hot encode form.

Some trained ANNs with different input parameters are included in subfolder ANNs, for corner periods T*=0.7, 1, and 1.2 seconds.

Hernández-Aguirre, V. M., Rupakhety, R., Paolucci, R., Vanini, M., & Smerzini, C. (2026). Hybrid broadband ground-motion simulation using neural networks with spatial, inter-period, and cross-component correlations.