

## Predictive Ground Motion Equations

Predictive ground motion equations (PGME) for median spectral acceleration generally have a form similar to the following:

$$\ln y = f_m(M) + f_d(R, M) + f_f(F) + f_s(S) + \varepsilon \cdot \sigma_T \quad (1)$$

Here  $f_m$ ,  $f_d$  and  $f_s$  represent the magnitude scaling, distance function and site amplification, respectively;  $f_f$  is a factor related to the source rupture mechanism. The predictive variables are  $M$ ,  $R$ , soil category or VS30 (average shear-wave velocity from the surface to a depth of 30 m); the fault type is an optional predictive variable that usually can be entered in the magnitude scaling term;  $\varepsilon$  is the fractional number of standard deviations of a single predicted value of  $\ln Y$ . Often, the overall aleatory uncertainty,  $\sigma_T$  is computed using the equation:

$$\sigma_T = \sqrt{\sigma^2 + \tau^2} \quad (2)$$

where  $\sigma$  is the intra-event aleatory uncertainty and  $\tau$  is the inter-event aleatory uncertainty.

Different regression models are proposed for the first two terms. Up to know, OHAZ can make it use four mathematical models:

$$1) \quad \ln y = b_1 + b_2 M + b_3 \ln(r + r_0) + b_4 (r + r_0) \quad (3)$$

(Ambraseys et al. 1996, Sabeta & Pugliese 1996, Berge-Thierry et a. 2003, Bindi et al. 2009, etc.)

$$2) \quad \ln y = b_1 + b_2 M + b_3 M^2 + (b_4 + b_5 M) \ln(r) \quad (4)$$

(Ambraseys et al. 2005, Akkar & Bommer 2007, etc.)

$$3) \quad \ln Y = b_1 + b_2 (M - 6) + b_3 (M - 6)^2 + b_4 \cdot r + b_5 \ln r \quad (5)$$

(Boore et al. 1997, etc).

$$4) \quad \ln y = f_m(M) + f_d(R, M) \quad (\text{Boore and Atkinson, NGA 2008}) \quad (6)$$

$$f_m(M) = \begin{cases} e_5(M - M_h) + e_6(M - M_h)^2, & M \leq M_h \\ e_7(M - M_h) + e_8(M - M_h)^2, & M > M_h \end{cases} \quad (7)$$

$$f_d(R, M) = [c_1 + c_2(M - M_{ref})] \ln(R / R_{ref}) + c_3(R - R_{ref}) + c_4(M - M_{ref})(R - R_{ref}) \quad (8)$$

In the above equations,  $r = \sqrt{d^2 + h_0^2}$ ,  $h_0$  (fixed depth) and  $r_0$  – are regression coefficients.

Later we plan to implement also some other mathematical models in use today.

Note that the distance is measured differently by different investigators. Ohaz use the epicentral ( $e$ ) distance, or the distance to the surface projection of the fault (Joyner and Boore, 1981), also known as fault distance ( $R_{JB}$ ).

For all the PGM models, the influence of fault type is characterized by the following equation:

$$f_f(F) = e_1 U + e_2 SS + e_3 NS + e_4 RS \quad (9)$$

where  $U$ ,  $SS$ ,  $NS$ ,  $RS$  are dummy variables used to denote unspecified, strike-slip, normal-slip, and reverse-slip fault type, respectively, as given by the values in Table 1, and  $M_h$ , the “hinge magnitude” for the shape of magnitude scaling, is a coefficient to be set during the analysis.

**Table 1.** Values of dummy variables for different fault types

Fault Type	U	SS	NS	RS
Unspecified	1	0	0	0
Strike-slip	0	1	0	0
Normal	0	0	1	0
Thrust/reverse	0	0	0	1

**Site response modelling**

The site amplification can be considered using one of the following models:

$$1. \text{ Discrete: } F_S(S) = b_{SA}SA + b_{SB}SB + b_{SC}SC + b_{SD}SD \quad (10)$$

$$2. \text{ Linear model: } F_S(V_{S30}) = b_{lin} \ln(V_{S30} / V_{ref}) \quad (11)$$

$$3. \text{ General model: } F_S(S) = F_{lin} + F_{NL} \quad (12)$$

In equation (10),  $SA$ ,  $SB$ ,  $SC$  and  $SD$  are dummy variables used to denote A, B, C, and D soil category (EC8 classes), respectively, as given by the values in Table 2. Generally, the term  $b_{SA}$  which corresponds to the rock class is included in the term  $b_I$  of the equations (3-4). Therefore, in the case of discrete model (10), OHAZ assumes that  $b_{SA}$  is included in the regression coefficient  $b_I$ , so the edit controls  $b_{SB}$  and  $b_{SC}$  in OHAZ represent the increments relative to rock condition, i.e.  $b_{SB} - b_{SA}$  and  $b_{SC} - b_{SA}$ , respectively.

**Table 2.** Values of dummy variables for different soil classes

Soil category	SA	SB	SC	SD
A ( $V_{S30} > 800\text{m/s}$ )	1	0	0	0
B ( $360 < V_{S30} \leq 800\text{m/s}$ )	0	1	0	0
C ( $180 < V_{S30} \leq 360\text{m/s}$ )	0	0	1	0
D ( $V_{S30} \leq 180\text{m/s}$ )	0	0	0	1

The need sometimes arises to evaluate GMPEs for a particular NEHRP site class. In the cases when the relevant PGM equation use the continuous variable  $V_{S30}$  as the predictor variable for site amplification, the

question naturally arises as to what value of  $V_{S30}$  to use for a specific NEHRP class. In the Table 3 are presented  $V_{S30}$  values (rounded) recommended by Boore and Atkinson (2008) for each NEHRP site class.

**Table 3.** Correspondence between NEHRP class and geometric mean  $V_{S30}$ 

NEHRP Site Class	Suggested $V_{S30}$ velocities	Geometric mean of NEHRP Class boundaries (rounded)
A	1880	
B	960	1070
C	490	525
D	250	255
E	150	

An alternative set of representative  $V_{S30}$  values for each NEHRP site class is given by the geometric mean of the velocities defining the site-class boundaries. These are given in the last column of Table 3.

Code used to identify the PGM equation and the distance

Code of PGMM		Equation	Example
Epicentral	Fault (R <sub>JB</sub> )		
1e	1f	3	Generic model (Ambraseys et al. 1996, etc.)
2e	2f	4	Ambraseys et al. 2005, Akkar & Bommer 2007.
3e	3f	5	Boore-Joyner-Fumal, 1997
4e	4f	6-8	Boore & Atkinson, 2008.

Code used to identify the response site model
0: Discrete model, Eq. (10)
1: Linear amplification, Eq.(11)
2: Nonlinear amplification, Eq. (12)

Often,  $\sigma$  (intra-event aleatory uncertainty) and  $\tau$  (the inter-event aleatory uncertainty) are magnitude dependent and can be calculated using the following regression equations:

$$\sigma = c_0 + c_1M, \text{ and } \tau = d_0 + d_1M$$

OHAZ uses three following models to characterize the aleatory uncertainties:

- 1)  $\sigma = c_0$  (constant, magnitude independent),
- 2)  $\sigma = c_0 + c_1M$  (magnitude dependent; not specified the intra- and inter uncertainty).
- 3)  $\sigma_\tau = \sqrt{\sigma^2 + \tau^2}$ , where  $\sigma = c_0 + c_1M$ ,  $\tau = d_0 + d_1M$

OHAZ 6.0 uses its database for a range of European and world-wide predictive ground motion models. The database is composed by a number of PGMM files, and the user can extend it with its preferred PGM models, following the procedure we have used to compile our database. To every PGMM in the database, corresponds a separate file (see the ....), which contains the following data:

ground motion parameter (PGA, PGV, SA), period, damping (%), code of the PGM model and of the distance used (e-epicentral, f-fault (Joyner-Boore)), code of the site response model, faulting mechanism (1=whether used, or 0=not used), code of the model used to calculate the mean square root of regression residuals, PGME regression coefficients, regression coefficient corresponding to the response site model and the faulting mechanism, and the equation coefficients characterising the aleatory uncertainty of the PGMM.

Every record of this file contains the PGM model for a given period, including PGA, PGV, or macroseismic Intensity). The structure of this file is shown in the appendices UpdatedSP96\_JB\_GH.atn, AkkBom07\_GM.atn, etc.). The information on the file names of the PGMM files available, is contained in the file *Attenuations.inf.*. The user can add to the attenuation database an unlimited number of the attenuations, providing the relevant file names in the *Attenuations.inf* file, and creating one file (named as in the relevant record in the *Attenuations.inffile*) for every additional PGM model (containing PGA, SA, etc), surely respecting the structure of the above mentioned attenuation files.

The user can specify the PGM models interactively, choosing the models from the database, or modifying and specifying the input parameters in the relevant controls (Attenuation page). He can also read one, or some attenuation relations at the same time) from the command file. The syntax of the relevant records can be easily seen choosing interactively two or three PGM models from the database ('Add UM' button) and than saving the Command file in a new file.