Chapter 4

GROUND MOTION

4.1 PROCEDURES FOR DETERMINING MAXIMUM CONSIDERED EARTHQUAKE AND DESIGN EARTHQUAKE GROUND MOTION ACCELERATIONS AND RESPONSE SPECTRA: Ground motion accelerations, represented by response spectra and coefficients derived from these spectra, shall be determined in accordance with the general procedure of Sec. 4.1.2 or the site-specific procedure of Sec. 4.1.3. The general procedure in which spectral response acceleration parameters for the *maximum considered earthquake ground motions* are derived using Maps 1 through 24, modified by site coefficients to include local site effects and scaled to design values, are permitted to be used for any *structure* except as specifically indicated in the *Provisions*. The site-specific procedure also is permitted to be used for any *structure* and shall be used where specifically required by the *Provisions*.

4.1.1 Maximum Considered Earthquake Ground Motions: The *maximum considered earthquake ground motions* shall be as represented by the mapped spectral response acceleration at short periods, S_S, and at 1 second, S_1, obtained from Maps 1 through 24 of the *Provisions*, respectively, and adjusted for *Site Class* effects using the site coefficients of Sec. 4.1.2.4. When a site-specific procedure is used, *maximum considered earthquake ground motion* shall be determined in accordance with Sec. 4.1.3.

4.1.2 General Procedure for Determining Maximum Considered Earthquake and Design Spectral Response Accelerations: The mapped *maximum considered earthquake* spectral response acceleration at short periods, S_S ,and at 1 second ,S_1, shall be determined from Maps 1 through 24.

For *structures* located within those regions of the maps having values of the short period spectral response acceleration, S_S, less than or equal to 0.15 and values of the 1 second period spectral response acceleration, S_1, less than or equal to 0.04, accelerations need not be determined. Such *structures* are permitted to be directly categorized as *Seismic Design Category* A in accordance with Sec. 4.2.1.

For all other *structures*, the *Site Class* shall be determined in accordance with Sec. 4.1.2.1. The *maximum considered earthquake* spectral response accelerations adjusted for *Site Class* effects, S_{MS} and S_{M1}, shall be determined in accordance with Sec. 4.1.2.4 and the design spectral response accelerations, S_{DS} and S_{D1}, shall be determined in accordance with Sec. 4.1.2.5. The general response spectrum, when required by the *Provisions*, shall be determined in accordance with Sec. 4.1.2.6.

4.1.2.1 Site Class Definitions: For all *structures* located within those regions of the maps having values of the short period spectral response acceleration, S_S, greater than 0.15 or values of the 1 second period spectral response acceleration, S_1, greater than 0.04, the site shall be classified as one of the following classes:

A Hard rock with measured shear wave velocity, $\overline{v}_s$ > 5,000 ft/sec (1500 m/s)

B Rock with 2,500 ft/sec < $\overline{v}_s$ ≤ 5,000 ft/sec (760 m/s < $\overline{v}_s$ ≤ 1500 m/s)

C Very dense soil and soft rock with 1,200 ft/sec < $\overline{v}_s$ ≤ 2,500 ft/sec (360 m/s < $\overline{v}_s$ ≤ 760 m/s) or with either $\overline{N}$ > 50 or $\overline{s}_u$ > 2,000 psf (100 kPa)

D Stiff soil with 600 ft/sec ≤ $\overline{v}_s$ ≤ 1,200 ft/sec (180 m/s ≤ $\overline{v}_s$ ≤ 360 m/s) or with either 15 ≤ $\overline{N}$ ≤ 50 or 1,000 psf ≤ $\overline{s}_u$ ≤ 2,000 psf (50 kPa ≤ $\overline{s}_u$ ≤ 100 kPa)

E A soil profile with $\overline{v}_s$ < 600 ft/sec (180 m/s) or with either

$\overline{N}$ < 15 $\overline{s}_u$ < 1,000 psf or any profile with more than 10 ft (3 m) of soft clay defined as soil with PI > 20, w ≥ 40 percent, and s_u < 500 psf (25 kPa)

F Soils requiring site-specific evaluations:

1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, and collapsible weakly cemented soils.

   Exception: For structures having fundamental periods of vibration equal to or less than 0.5 second, site-specific evaluations are not required to determine spectral accelerations for liquefiable soils. Rather, the *Site Class* may be determined in accordance with Sec. 4.1.2.2 and the corresponding values of F_a and F_v determined from Tables 4.1.2.4a and 4.1.2.4b.

2. Peats and/or highly organic clays (H > 10 ft [3 m] of peat and/or highly organic clay where H = thickness of soil)

3. Very high plasticity clays (H > 25 ft [8 m] with PI > 75)

4. Very thick soft/medium stiff clays (H > 120 ft [36 m])

When the soil properties are not known in sufficient detail to determine the *Site Class*, *Site Class* D shall be used. *Site Classes* E or F need not be assumed unless the authority having jurisdiction determines that *Site Classes* E or F could be present at the site or in the event that *Site Classes* E or F are established by geotechnical data.

4.1.2.2 Steps for Classifying a Site (also see Table 4.1.2.2 below):

Step 1: Check for the four categories of *Site Class* F requiring site-specific evaluation. If the site corresponds to any of these categories, classify the site as *Site Class* F and conduct a site-specific evaluation.

Step 2: Check for the existence of a total thickness of soft clay > 10 ft (3 m) where a soft clay layer is defined by: s_u < 500 psf (25 kPa), w ≥ 40 percent, and PI > 20. If these criteria are satisfied, classify the site as *Site Class* E.

Step 3: Categorize the site using one of the following three methods with $\overline{v}_s$, $\overline{N}$, and $\overline{s}_u$ computed in all cases as specified by the definitions in Sec. 4.1.2.2:

a. $\overline{v}_s$ for the top 100 ft (30 m) ($\overline{v}_s$ method)

b. $\overline{N}$ for the top 100 ft (30 m) ($\overline{N}$ method)

c. $\bar{N}_{ch}$ for cohesionless soil layers (PI < 20) in the top 100 ft (30 m) and average $\bar{s}_u$ for cohesive soil layers (PI > 20) in the top 100 ft (30 m) ($\bar{s}_u$ method).

TABLE 4.1.2.2 Site Classification

Site Class	$\bar{v}_s$	$\bar{N}$ **or** $\bar{N}_{ch}$	$\bar{s}_u$
E	< 600 fps (< 180 m/s)	< 15	< 1,000 psf (< 50 kPa)
D	600 to 1,200 fps (180 to 360 m/s)	15 to 50	1,000 to 2,000 psf (50 to 100 kPa)
C	> 1,200 to 2,500 fps (360 to 760 m/s)	> 50	> 2,000 (> 100 kPa)

NOTE: If the $\bar{s}_u$ method is used and the $\bar{N}_{ch}$ and $\bar{s}_u$ criteria differ, select the category with the softer soils (e.g., use *Site Class* E instead of D).

The shear wave velocity for rock, *Site Class* B, shall be either measured on site or estimated for competent rock with moderate fracturing and weathering. Softer and more highly fractured and weathered rock shall either be measured on site for shear wave velocity or classified as *Site Class* C.

The hard rock category, *Site Class* A, shall be supported by shear wave velocity measurements either on site or on profiles of the same rock type in the same formation with an equal or greater degree of weathering and fracturing. Where hard rock conditions are known to be continuous to a depth of 100 ft (30 m), surficial shear wave velocity measurements may be extrapolated to assess $\bar{v}_s$.

The rock categories, *Site Classes* A and B, shall not be used if there is more than 10 ft (3 m) of soil between the rock surface and the bottom of the spread footing or mat foundation.

4.1.2.3 Definitions of Site Class Parameters: The definitions presented below apply to the upper 100 ft (30 m) of the site profile. Profiles containing distinctly different soil layers shall be subdivided into those layers designated by a number that ranges from 1 to *n* at the bottom where there are a total of *n* distinct layers in the upper 100 ft (30 m). The symbol *i* then refers to any one of the layers between 1 and *n*.

v_{si} is the shear wave velocity in ft/sec (m/s).

d_i is the thickness of any layer between 0 and 100 ft (30 m),

$\bar{v}_s$ is:

$$\bar{v}_s = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}} \qquad (4.1.2.3\text{-}1)$$

where $\sum_{i=1}^{n} d_i$ is equal to 100 ft (30 m)

N_i is the Standard Penetration Resistance (ASTM D1586-84) not to exceed 100 blows/ft as directly measured in the field without corrections.

$\overline{N}$ is:

$$\overline{N} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{N_i}} \qquad (4.1.2.3\text{-}2)$$

$\overline{N}_{ch}$ is:

$$\overline{N_{ch}} = \frac{d_s}{\sum_{i=1}^{m} \frac{d_i}{N_i}} \qquad (4.1.2.3\text{-}3)$$

where $\sum_{i=1}^{m} d_i = d_s$.

(Use only d_i and N_i for cohesionless soils.)

d_s is the total thickness of cohesionless soil layers in the top 100 ft (30 m).

s_{ui} is the undrained shear strength in psf (kPa), not to exceed 5,000 psf (250 kPa), ASTM D2166-91 or D2850-87.

$\overline{s}_u$ is:

$$\overline{s}_u = \frac{d_c}{\sum_{i=1}^{k} \frac{d_i}{s_{ui}}} \qquad (4.1.2.3\text{-}4)$$

where $\sum_{i=1}^{k} d_i = d_c$.

d_c is the total thickness (100 - d_s) of cohesive soil layers in the top 100 ft (30 m).

PI is the plasticity index, ASTM D4318-93.

w is the moisture content in percent, ASTM D2216-92.

4.1.2.4 Site Coefficients and Adjusted Maximum Considered Earthquake Spectral Response Acceleration Parameters: The *maximum considered earthquake* spectral response acceleration for short periods, S_{MS}, and at 1 second, S_{M1}, adjusted for *site class* effects, shall be determined by Eq. 4.1.2.4-1 and 4.1.2.4-2, respectively:

$$S_{MS} = F_a S_s \qquad (4.1.2.4\text{-}1)$$

and

$$S_{M1} = F_v S_1 \qquad (4.1.2.4\text{-}2)$$

where *site coefficients* F_a and F_v are defined in Tables 4.1.2.4a and b, respectively.

TABLE 4.1.2.4a Values of F_a as a Function of Site Class and Mapped Short-Period Maximum Considered Earthquake Spectral Acceleration

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration at Short Periods				
	$S_S \le 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration at Short Periods				
	$S_S \le 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \ge 1.25$
F	*a*	*a*	*a*	*a*	*a*

NOTE: Use straight line interpolation for intermediate values of S_S.

[a] Site-specific geotechnical investigation and dynamic site response analyses shall be performed. Exception: For structures with periods of vibration equal to or less than 0.5 second, values of F_a for liquefiable soils may be assumed equal to the values for the *Site Class* determined without regard to liquefaction in Step 3 of Sec. 4.1.2.2.

TABLE 4.1.2.4b Values of F_v as a Function of Site Class and Mapped 1 Second Period Maximum Considered Earthquake Spectral Acceleration

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration at 1 Second Periods				
	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	*a*	*a*	*a*	*a*	*a*

NOTE: Use straight line interpolation for intermediate values of S_1.

[a] Site-specific geotechnical investigation and dynamic site response analyses shall be performed. Exception: For structures with periods of vibration equal to or less than 0.5 second, values of F_v for liquefiable soils may be assumed equal to the values for the *Site Class* determined without regard to liquefaction in Step 3 of Sec. 4.1.2.2.

4.1.2.5 Design Spectral Response Acceleration Parameters: *Design earthquake* spectral response acceleration at short periods, S_{DS} , and at 1 second period, S_{D1}, shall be determined from Eq. 4.1.2.5-1 and 4.1.2.5-2, respectively:

$$S_{DS} = \frac{2}{3} S_{MS} \qquad (4.1.2.5\text{-}1)$$

and

$$S_{D1} = \frac{2}{3} S_{M1} \qquad (4.1.2.5\text{-}2)$$

4.1.2.6 General Procedure Response Spectrum: Where a design response spectrum is required by the *Provisions* and site-specific procedures are not used, the design response spectrum curve shall be developed as indicated in Figure 4.1.2.6 and as follows:

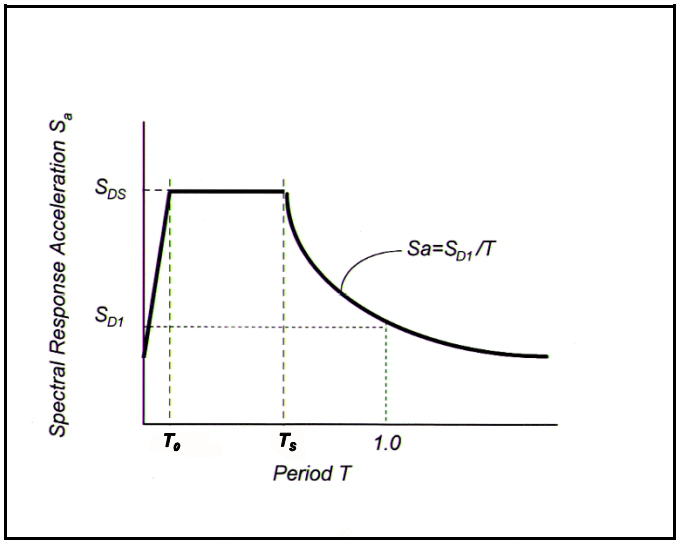

FIGURE 4.1.2.6 Design response spectrum.

1. For periods less than or equal to T_0, the design spectral response acceleration, S_a, shall be taken as given by Eq. 4.1.2.6-1:

$$S_a = 0.6\frac{S_{DS}}{T_o}T + 0.4\,S_{DS} \qquad (4.1.2.6\text{-}1)$$

2. For periods greater than or equal to T_0 and less than or equal to T_S, the design spectral response acceleration, S_a, shall be taken as equal to S_{DS}.

3. For periods greater than T_S, the design spectral response acceleration, S_a, shall be taken as given by Eq. 4.1.2.6-3:

$$S_a = \frac{S_{D1}}{T} \qquad (4.1.2.6\text{-}3)$$

where:

S_{DS} = the design spectral response acceleration at short periods,

S_{D1} = the design spectral response acceleration at 1 second period,

T = the fundamental period of the *structure* (sec),

T_0 = $0.2S_{D1}/S_{DS}$, and

T_S = S_{D1}/S_{DS}.

4.1.3 Site-Specific Procedure for Determining Ground Motion Accelerations: A site-specific study shall account for the regional seismicity and geology, the expected recurrence rates and maximum magnitudes of events on known faults and source zones, the location of the site with respect to these, near source effects if any, and the characteristics of subsurface site conditions.

4.1.3.1 Probabilistic Maximum Considered Earthquake: When site-specific procedures are utilized, the *maximum considered earthquake ground motion* shall be taken as that motion represented by a 5 percent damped acceleration response spectrum having a 2 percent probability of exceedance within a 50 year period. The *maximum considered earthquake* spectral response acceleration, S_{aM}, at any period, T, shall be taken from that spectrum.

Exception: Where the spectral response ordinates for a 5 percent damped spectrum having a 2 percent probability of exceedance within a 50 year period at periods of 0.2 second or 1 second exceed the corresponding ordinate of the deterministic limit of Sec. 4.1.3.2, the *maximum considered earthquake ground motion* shall be taken as the lesser of the probabilistic *maximum considered earthquake ground motion* or the deterministic *maximum considered earthquake ground motion* of Sec. 4.1.3.3 but shall not be taken less than the deterministic limit ground motion of Sec. 4.1.3.2.

4.1.3.2 Deterministic Limit on Maximum Considered Earthquake Ground Motion: The deterministic limit on *maximum considered earthquake ground motion* shall be taken as the response spectrum determined in accordance with Figure 4.1.3.2, where F_a and F_v are determined in accordance with Sec. 4.1.2.4 with the value of S_S taken as 1.5 and the value of S_1 taken as 0.6.

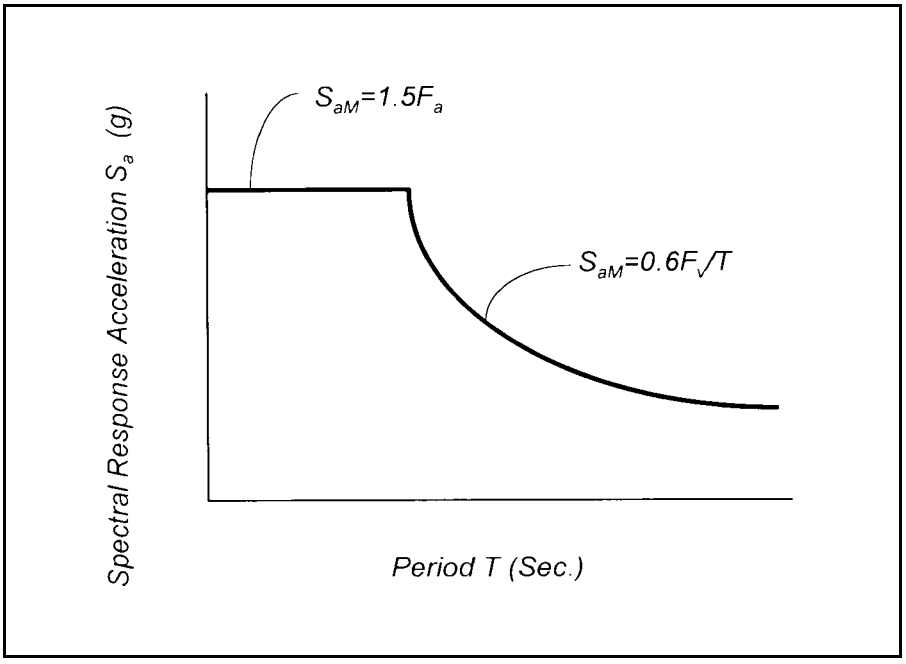

FIGURE 4.1.3.2 Deterministic limit on maximum considered earthquake response spectrum.

4.1.3.3 Deterministic Maximum Considered Earthquake Ground Motion: The deterministic *maximum considered earthquake ground motion* response spectrum shall be calculated as 150 percent of the median 5 percent damped spectral response accelerations, S_{aM}, at all periods resulting from a characteristic earthquake on any known active fault within the region.

4.1.3.5 Site-Specific Design Ground Motion: Where site-specific procedures are used to determine the *maximum considered earthquake ground motion* response spectrum, the design spectral response acceleration at any period shall be determined from Eq. 4.1.3.5:

$$S_a = \frac{2}{3} S_{aM} \qquad (4.1.3.5)$$

and shall be greater than or equal to 80 percent of the S_a determined by the general response spectrum in Sec. 4.1.2.6.

4.2 SEISMIC DESIGN CATEGORY: Each *structure* shall be assigned a *Seismic Design Category* in accordance with Sec. 4.2.1. *Seismic Design Categories* are used in the *Provisions* to determine permissible structural systems, limitations on height and irregularity, those components of the *structure* that must be designed for seismic resistance, and the types of lateral force analysis that must be performed.

4.2.1 Determination of Seismic Design Category: All *structures* shall be assigned to a *Seismic Design Category* based on their *Seismic Use Group* and the design spectral response acceleration coefficients, S_{DS} and S_{D1}, determined in accordance with Sec. 4.1.2.5. Each *building* and *structure* shall be assigned to the most severe *Seismic Design Category* in accordance with Table 4.2.1a or 4.2.1b, irrespective of the fundamental period of vibration of the *structure, T*.

TABLE 4.2.1a Seismic Design Category Based on Short Period Response Accelerations

Value of S_{DS}	Seismic Use Group		
	I	**II**	**III**
$S_{DS} < 0.167$	A	A	A
$0.167 \le S_{DS} < 0.33$	B	B	C
$0.33 \le S_{DS} < 0.50$	C	C	D
$0.50 \le S_{DS}$	D [a]	D [a]	D [a]

[a] *Seismic Use Group* I and II *structures* located on sites with mapped *maximum considered earthquake* spectral response acceleration at 1 second period, S_1, equal to or greater than 0.75 shall be assigned to *Seismic Design Category* E and *Seismic Use Group* III *structures* located on such sites shall be assigned to *Seismic Design Category* F.

TABLE 4.2.1b Seismic Design Category Based on 1 Second Period Response Accelerations

Value of S_{D1}	Seismic Use Group		
	I	**II**	**III**
$S_{D1} < 0.067$	A	A	A
$0.067 \le S_{D1} < 0.133$	B	B	C
$0.133 \le S_{D1} < 0.20$	C	C	D
$0.20 \le S_{D1}$	D [a]	D [a]	D [a]

[a] *Seismic Use Group* I and II *structures* located on sites with mapped *maximum considered earthquake* spectral response acceleration at 1 second period, S_1, equal to or greater than 0.75 shall be assigned to *Seismic Design Category* E and *Seismic Use Group* III *structures* located on such sites shall be assigned to *Seismic Design Category* F.

4.2.2 Site Limitation for Seismic Design Categories E and F: A *structure* assigned to *Seismic Design Category* E or F shall not be sited where there is the potential for an active fault to cause rupture of the ground surface at the *structure*.

Exception: Detached one- and two-family dwellings of light-frame construction.