- **Class C:** Very dense soil and soft rock with $1{,}200 \text{ ft/sec} < \bar{v}_s \leq 2{,}500 \text{ ft/sec}$ or with either standard blow count $\bar{N} > 50$ or undrained shear strength $\bar{s}_u > 2{,}000 \text{ psf}$

- **Class D:** Stiff soil with $600 \text{ ft/sec} < \bar{v}_s \leq 1{,}200 \text{ ft/sec}$ or with $15 < \bar{N} \leq 50$ or $1{,}000 \text{ psf} \leq \bar{s}_u < 2{,}000$ psf

- **Class E:** Any profile with more than 10 feet of soft clay defined as soil with plasticity index $PI > 20$, or water content w > 40 percent, and $\bar{s}_u < 500$ psf or a soil profile with $\bar{v}_s < 600 \text{ ft/sec}$. If insufficient data are available to classify a soil profile as type A through D, a type E profile should be assumed.

- **Class F:** Soils requiring site-specific evaluations:

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

  – Peats and/or highly organic clays (H > 10 feet of peat and/or highly organic clay, where H = thickness of soil)

  – Very high plasticity clays (H > 25 feet with PI > 75 percent)

  – Very thick soft/medium stiff clays (H > 120 feet)

The parameters $\bar{v}_s$, $\bar{N}$, and $\bar{s}_u$ are, respectively, the average values of the shear wave velocity, Standard Penetration Test (SPT) blow count, and undrained shear strength of the upper 100 feet of soils at the site. These values may be calculated from Equation 2-6, below:

$$\bar{v}_s, \bar{N}, \bar{s}_u = \frac{\displaystyle\sum_{i=1}^{n} d_i}{\displaystyle\sum_{i=1}^{n} \frac{d_i}{v_{si}}, \frac{d_i}{N_i}, \frac{d_i}{s_{ui}}} \qquad (2\text{-}6)$$

where:

N_i = SPT blow count in soil layer "i"

n = Number of layers of similar soil materials for which data is available

d_i = Depth of layer "i"

s_{ui} = Undrained shear strength in layer "i"

v_{si} = Shear wave velocity of the soil in layer "i"

and

$$\sum_{i=1}^{n} d_i = 100 \ ft \qquad (2\text{-}7)$$

Where reliable v_s data are available for the site, such data should be used to classify the site. If such data are not available, N data should preferably be used for cohesionless soil sites (sands, gravels), and s_u data for cohesive soil sites (clays). For rock in profile classes B and C, classification may be based either on measured or estimated values of v_s. Classification of a site as Class A rock should be based on measurements of v_s either for material at the site itself, or for similar rock materials in the vicinity; otherwise, Class B rock should be assumed. Class A or B profiles should not be assumed to be present if there is more than 10 feet of soil between the rock surface and the base of the building.

2.6.1.5 General Response Spectrum

A general, horizontal response spectrum may be constructed by plotting the following two functions in the spectral acceleration vs. structural period domain, as shown in Figure 2-1. Where a vertical response spectrum is required, it may be constructed by taking two-thirds of the spectral ordinates, at each period, obtained for the horizontal response spectrum.

$$S_a = (S_{XS}/B_S)(0.4 + 3T/T_o)$$
$$\text{for } 0 < T \leq 0.2T_o \qquad (2\text{-}8)$$

$$S_a = (S_{X1}/(B_1 T)) \text{ for } T > T_o \qquad (2\text{-}9)$$
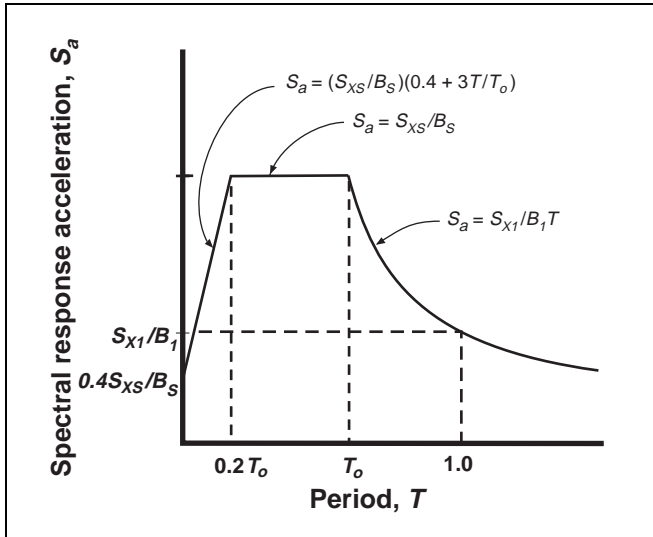
Figure 2-1   *General Response Spectrum*

where T_o is given by the equation

$$T_o = (S_{X1}B_S)/(S_{XS}B_1) \qquad (2\text{-}10)$$

where B_S and B_1 are taken from Table 2-15.

Table 2-15   *Damping Coefficients B_S and B_1 as a Function of Effective Damping β*

Effective Damping β (percentage of critical)[1]	B_S	B_1
< 2	0.8	0.8
5	1.0	1.0
10	1.3	1.2
20	1.8	1.5
30	2.3	1.7
40	2.7	1.9
> 50	3.0	2.0

1. The damping coefficient should be based on linear interpolation for effective damping values other than those given.

In general, it is recommended that a 5% damped response spectrum be used for the rehabilitation design of most buildings and structural systems. Exceptions are as follows:

- For structures without exterior cladding an effective viscous damping ration, β, of 2% should be assumed.

- For structures with wood diaphragms and a large number of interior partitions and cross walls that interconnect the diaphragm levels, an effective viscous damping ratio, β, of 10% may be assumed.

- For structures rehabilitated using seismic isolation technology or enhanced energy dissipation technology, an equivalent effective viscous damping ratio, β, should be calculated using the procedures contained in Chapter 9.

In Chapter 9 of the *Guidelines*, the analytical procedures for structures rehabilitated using seismic isolation and/or energy dissipation technology make specific reference to the evaluation of earthquake demands for the BSE-2 and user-specified design earthquake hazard levels. In that chapter, the parameters: S_{aM}, S_{MS}, S_{M1}, refer respectively to the value of the spectral response acceleration parameters S_a, S_{XS}, and S_{X1}, evaluated for the BSE-2 hazard level, and the parameters S_{aD}, S_{DS}, S_{D1} in Chapter 9, refer respectively to the value of the spectral response acceleration parameters S_a, S_{XS}, and S_{X1}, evaluated for the user-specified design earthquake hazard level.

2.6.2   Site-Specific Ground Shaking Hazard

Where site-specific ground shaking characterization is used as the basis of rehabilitation design, the characterization shall be developed in accordance with this section.

2.6.2.1   Site-Specific Response Spectrum

Development of site-specific response spectra shall be based on the geologic, seismologic, and soil characteristics associated with the specific site. Response spectra should be developed for an equivalent viscous damping ratio of 5%. Additional spectra should be developed for other damping ratios appropriate to the indicated structural behavior, as discussed in Section 2.6.1.5. When the 5% damped site-specific spectrum has spectral amplitudes in the period range of greatest significance to the structural response that are less than 70 percent of the spectral amplitudes of the General Response Spectrum, an independent third-party review of the spectrum should be made by an individual with expertise in the evaluation of ground motion.

When a site-specific response spectrum has been developed and other sections of these *Guidelines* require values for the spectral response parameters, S_{XS}, S_{X1}, or T_0, they may be obtained in accordance with this section. The value of the design spectral response acceleration at short periods, S_{XS}, shall be taken as the response acceleration obtained from the site-specific spectrum at a period of 0.2 seconds, except that it should be taken as not less than 90% of the peak response acceleration at any period. In order to obtain a value for the design spectral response acceleration parameter S_{X1}, a curve of the form $S_a = S_{X1}/T$ should be graphically overlaid on the site-specific spectrum such that at any period, the value of S_a obtained from the curve is not less than 90% of that which would be obtained directly from the spectrum. The value of T_0 shall be determined in accordance with Equation 2-11. Alternatively, the values obtained in accordance with Section 2.6.1 may be used for all of these parameters.

$$T_0 = S_{X1}/S_{XS} \qquad (2\text{-}11)$$

2.6.2.2 Acceleration Time Histories

Time-History Analysis shall be performed with no fewer than three data sets (two horizontal components or, if vertical motion is to be considered, two horizontal components and one vertical component) of appropriate ground motion time histories that shall be selected and scaled from no fewer than three recorded events. Appropriate time histories shall have magnitude, fault distances, and source mechanisms that are consistent with those that control the design earthquake ground motion. Where three appropriate recorded ground-motion time history data sets are not available, appropriate simulated time history data sets may be used to make up the total number required. For each data set, the square root of the sum of the squares (SRSS) of the 5%-damped site-specific spectrum of the scaled horizontal components shall be constructed. The data sets shall be scaled such that the average value of the SRSS spectra does not fall below 1.4 times the 5%-damped spectrum for the design earthquake for periods between $0.2T$ seconds and $1.5T$ seconds (where T is the fundamental period of the building).

Where three time history data sets are used in the analysis of a structure, the maximum value of each response parameter (e.g., force in a member, displacement at a specific level) shall be used to determine design acceptability. Where seven or more time history data sets are employed, the average value of each response parameter may be used to determine design acceptability.

2.6.3 Seismicity Zones

In these *Guidelines*, seismicity zones are defined as follows.

2.6.3.1 Zones of High Seismicity

Buildings located on sites for which the 10%/50 year, design short-period response acceleration, S_{XS}, is equal to or greater than 0.5g, or for which the 10%/50 year design one-second period response acceleration, S_{X1}, is equal to or greater than 0.2g shall be considered to be located within zones of high seismicity.

2.6.3.2 Zones of Moderate Seismicity

Buildings located on sites for which the 10%/50 year, design short-period response acceleration, S_{XS}, is equal to or greater than 0.167g but is less than 0.5g, or for which the 10%/50 year, design one-second period response acceleration, S_{X1}, is equal to or greater than 0.067g but less than 0.2g shall be considered to be located within zones of moderate seismicity.

2.6.3.3 Zones of Low Seismicity

Buildings located on sites that are not located within zones of high or moderate seismicity, as defined in Sections 2.6.3.1 and 2.6.3.2, shall be considered to be located within zones of low seismicity.

2.6.4 Other Seismic Hazards

In addition to ground shaking, seismic hazards can include ground failure caused by surface fault rupture, liquefaction, lateral spreading, differential settlement, and landsliding. Earthquake-induced flooding, due to tsunami, seiche, or failure of a water-retaining structure, can also pose a hazard to a building site. The process of rehabilitating a building shall be based on the understanding that either the site is not exposed to a significant earthquake-induced flooding hazard or ground failure, or the site may be stabilized or protected from such hazards at a cost that is included along with the other rehabilitation costs. Chapter 4 describes, and provides guidance for evaluating and mitigating, these and other on-site and off-site seismic hazards.