Earthquake Loads and the IBC Seismic Force Procedure

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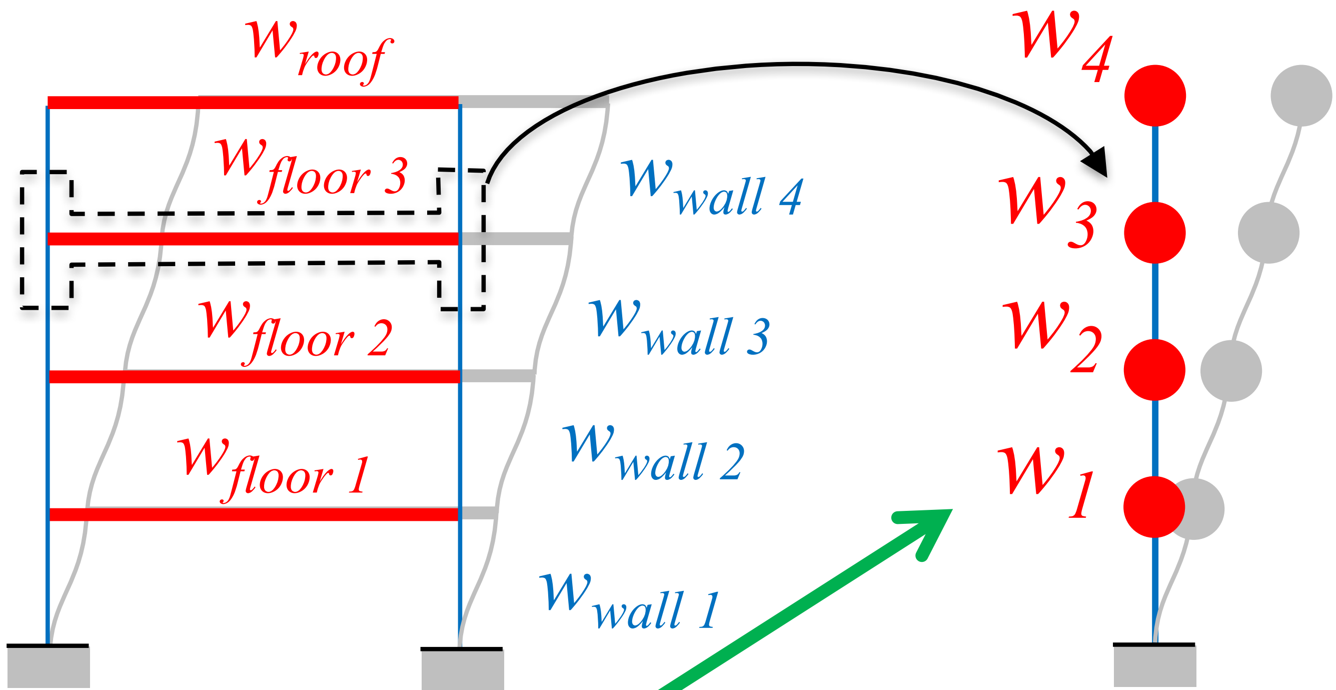
Dynamic Model of a Building Structure



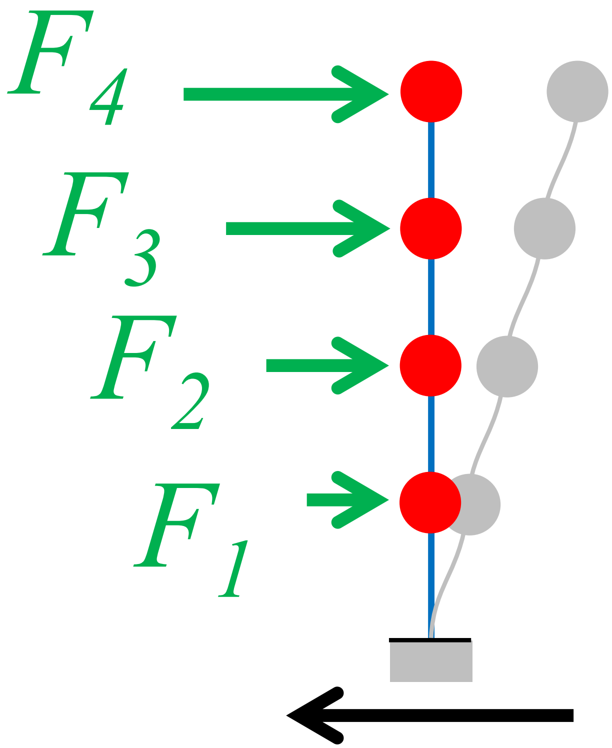
Weight of building is lumped at floor levels

$$w_3 = w_{floor\ 3} + \frac{1}{2}(w_{wall\ 4}) + \frac{1}{2}(w_{wall\ 3})$$

Total Seismic Weight of Building

$$W = w_1 + w_2 + w_3 + w_4$$

Equivalent Static Seismic Forces and Seismic Base Shear



Seismic Base Shear

$$V = F_1 + F_2 + F_3 + F_4$$

IBC Base Shear Expression

$$V = \left[\frac{I_e(S_{DS})}{R}\right] W \quad \text{for} \quad T \le T_S$$

$$V = \left[\frac{I_e(S_{D1})}{TR}\right] W \quad \text{for} \quad T > T_S$$

$$T_S = \frac{S_{D1}}{S_{DS}}$$

Seismic Base Shear (V) depends on:

1. The seismic weight of the building (W);
2. The fundamental period of vibration of the building (T);
3. The earthquake acceleration at the base of the building (S_{DS} and S_{D1});
4. The energy dissipating capacity of the lateral force resisting system (R);
5. The desired performance level of the building (I_e).

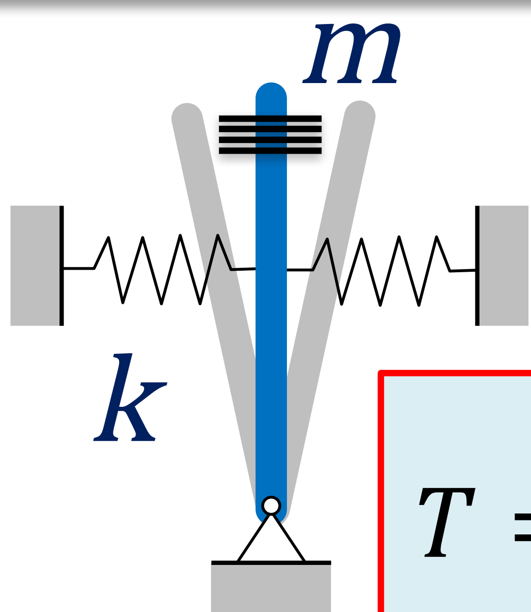
Fundamental Period of Vibration

Properties of structures that are important in defining vibratory response to dynamic loading are:

- Mass (m),
- Stiffness, (k) and
- Damping or energy dissipation (c).

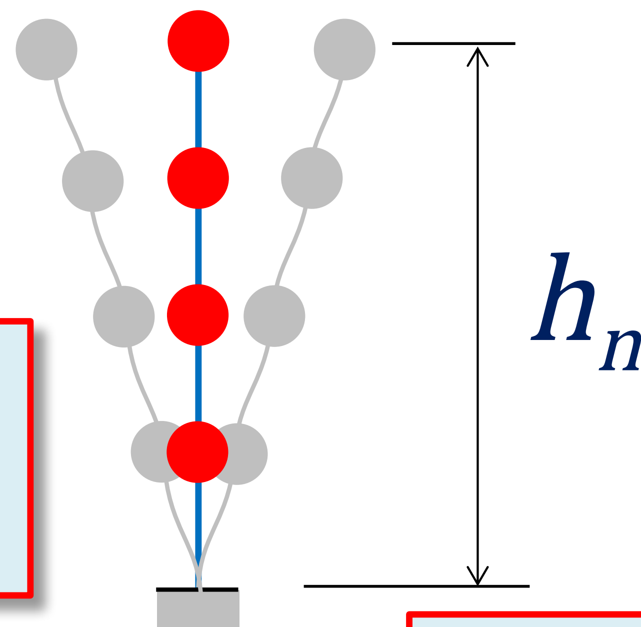
Fundamental Period of Vibration

Single Degree of Freedom System



$$T = 2\pi\sqrt{\frac{m}{k}}$$

Building – Multiple Degree of Freedom System



$$T = C_t h_n^x$$

Period is the time it takes to complete one cycle of vibration

Vibration will stop due to damping

IBC Estimate of the Fundamental Period of Vibration of a Building

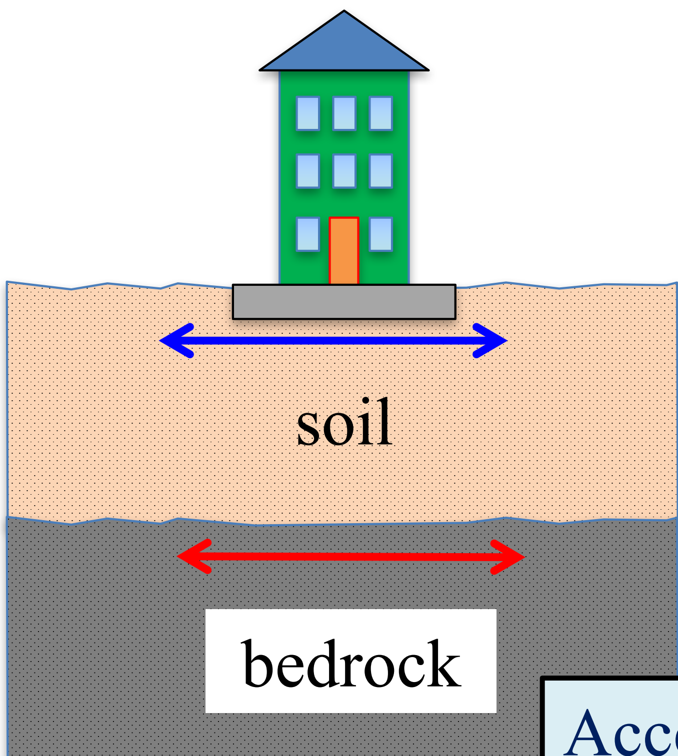
$$T = C_t h_n^x$$

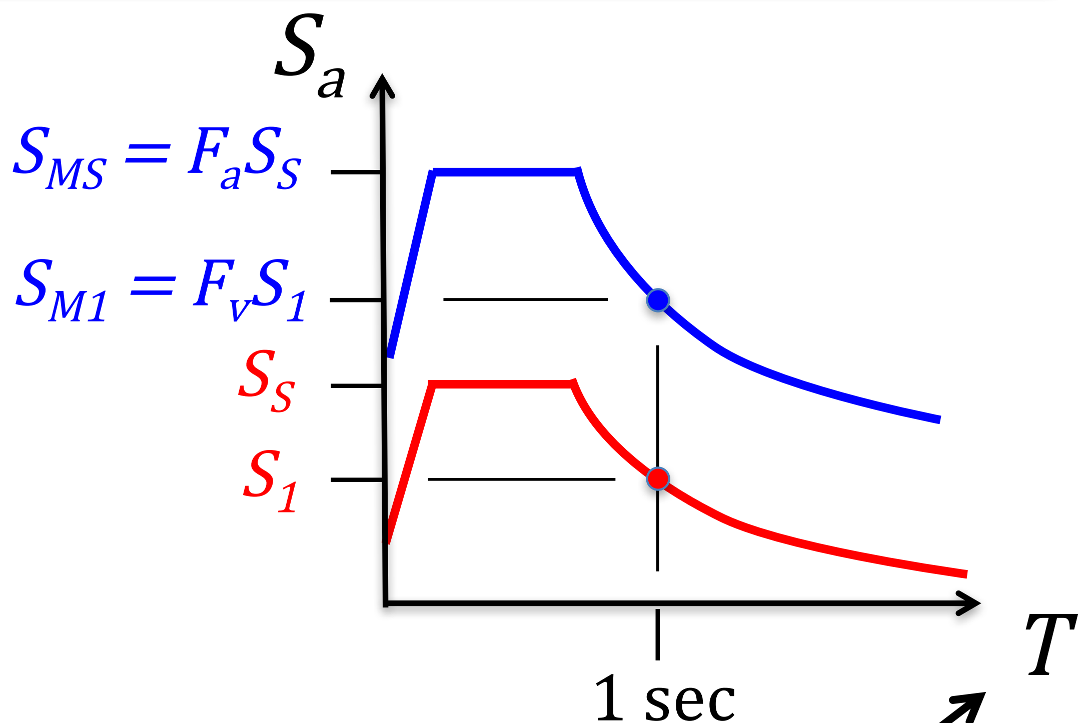
h_n = average roof height of the building

C_t and x are based on the stiffness and dynamic characteristics of the lateral force resisting system

Earthquake Acceleration at the Base of the Building

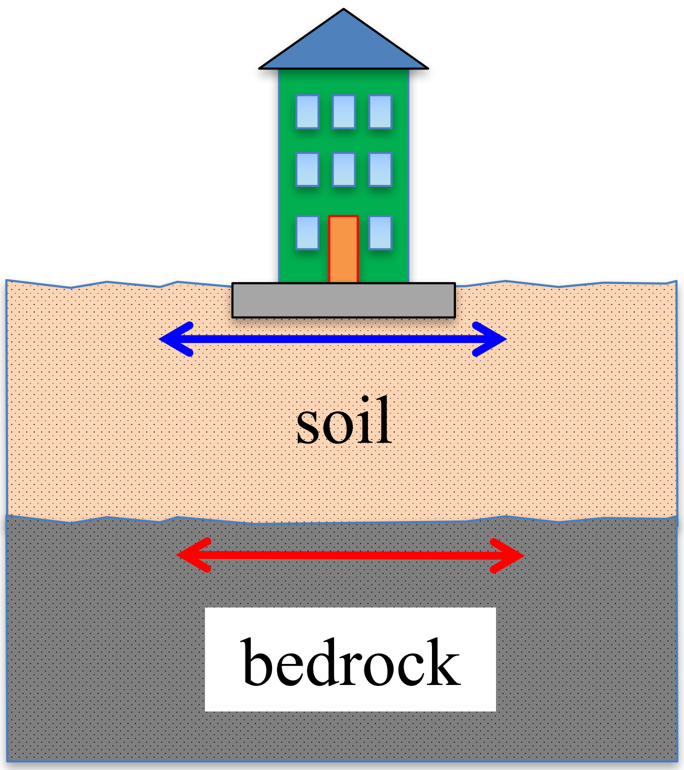
Maximum acceleration at the base of the building depends on the seismicity of the site and the soil at the site

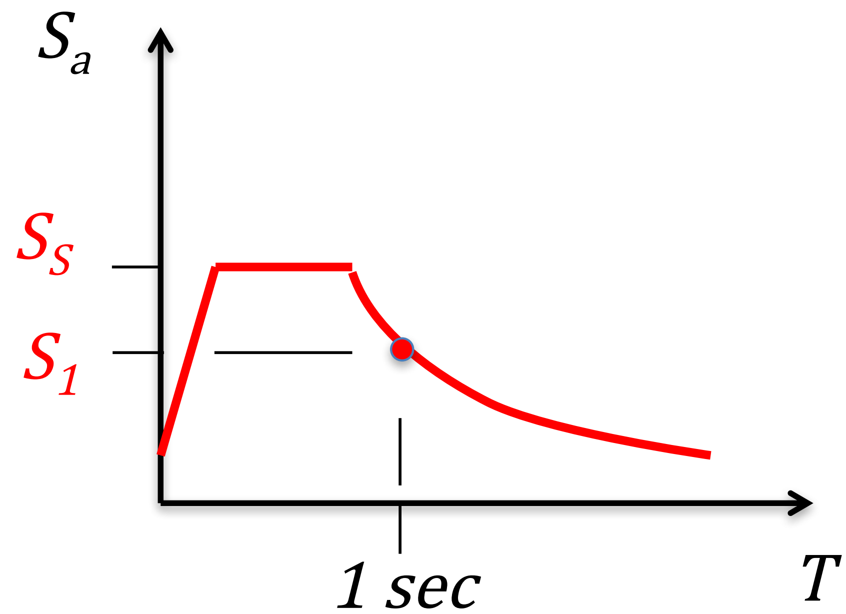




Acceleration is a function of the fundamental period of the building

Acceleration at the bedrock level depends on seismicity of the site





Acceleration at bedrock
S_S and S_1 from
IBC Figures 1613.5 (3 and 4)

S_S from IBC Figure 1613.5 (3)

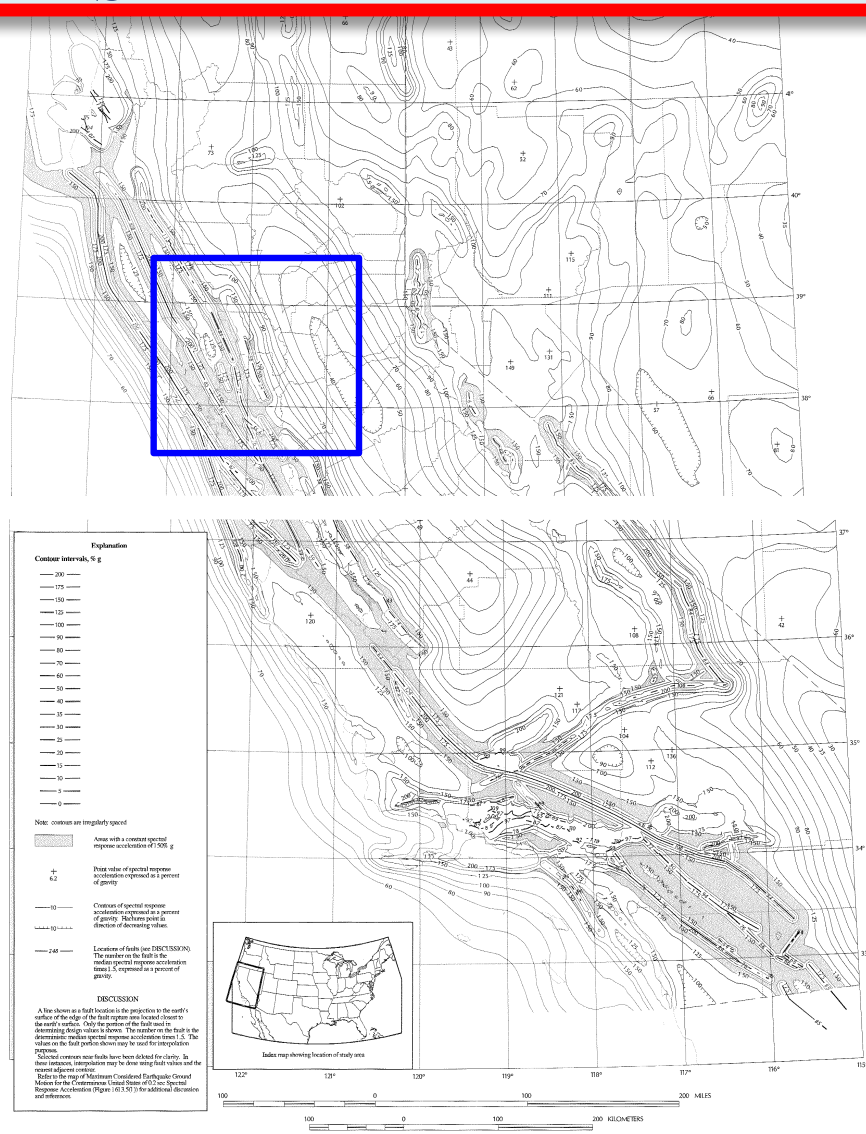
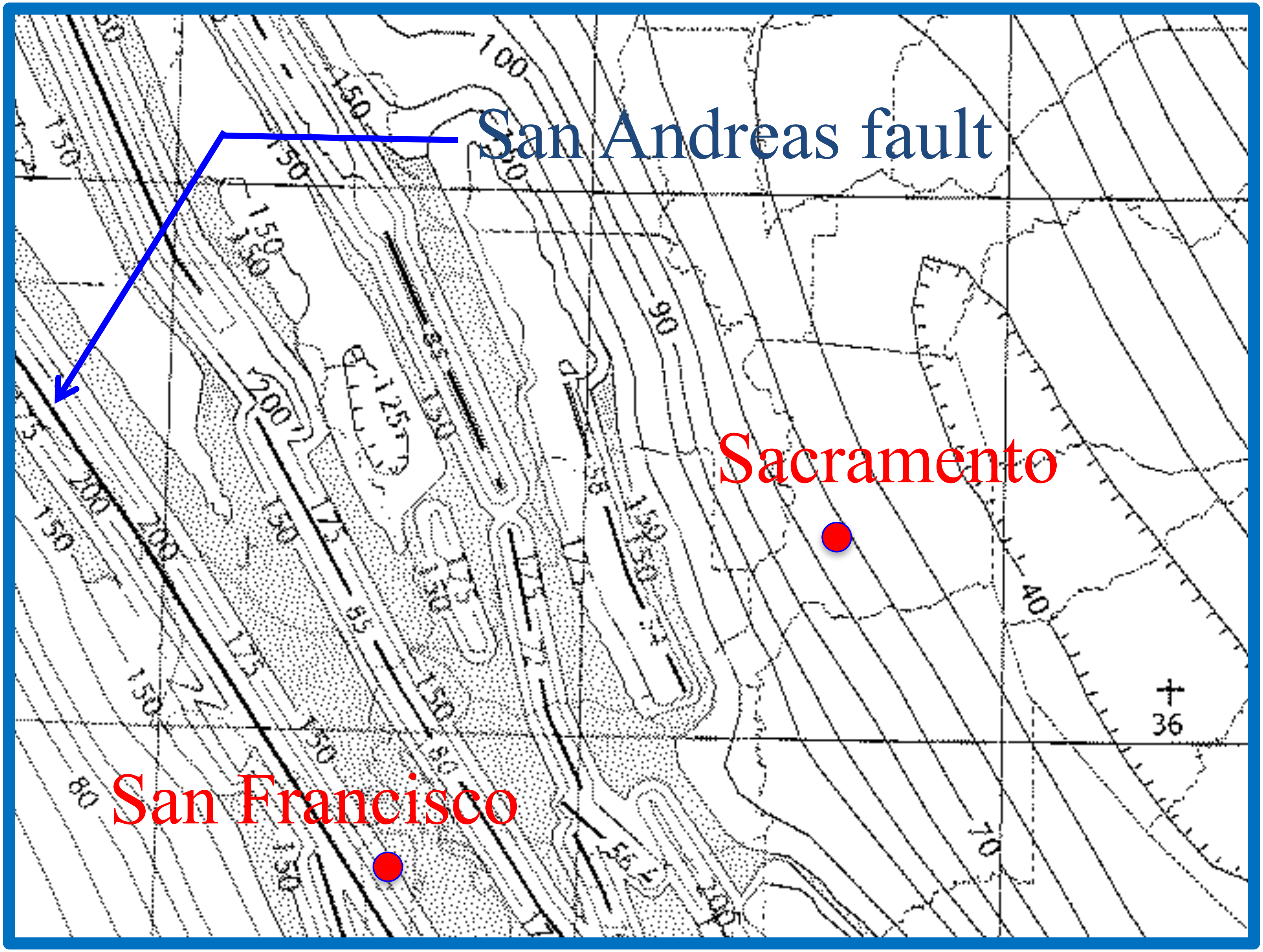


FIGURE 1613.5(3)—continued
MAXIMUM CONSIDERED EARTHQUAKE GROUND MOTION FOR REGION 1 OF
0.2 SEC SPECTRAL RESPONSE ACCELERATION (5% OF CRITICAL DAMPING), SITE CLASS B


San Andreas fault
Sacramento
San Francisco

S_1 from IBC Figure 1613.5 (4)

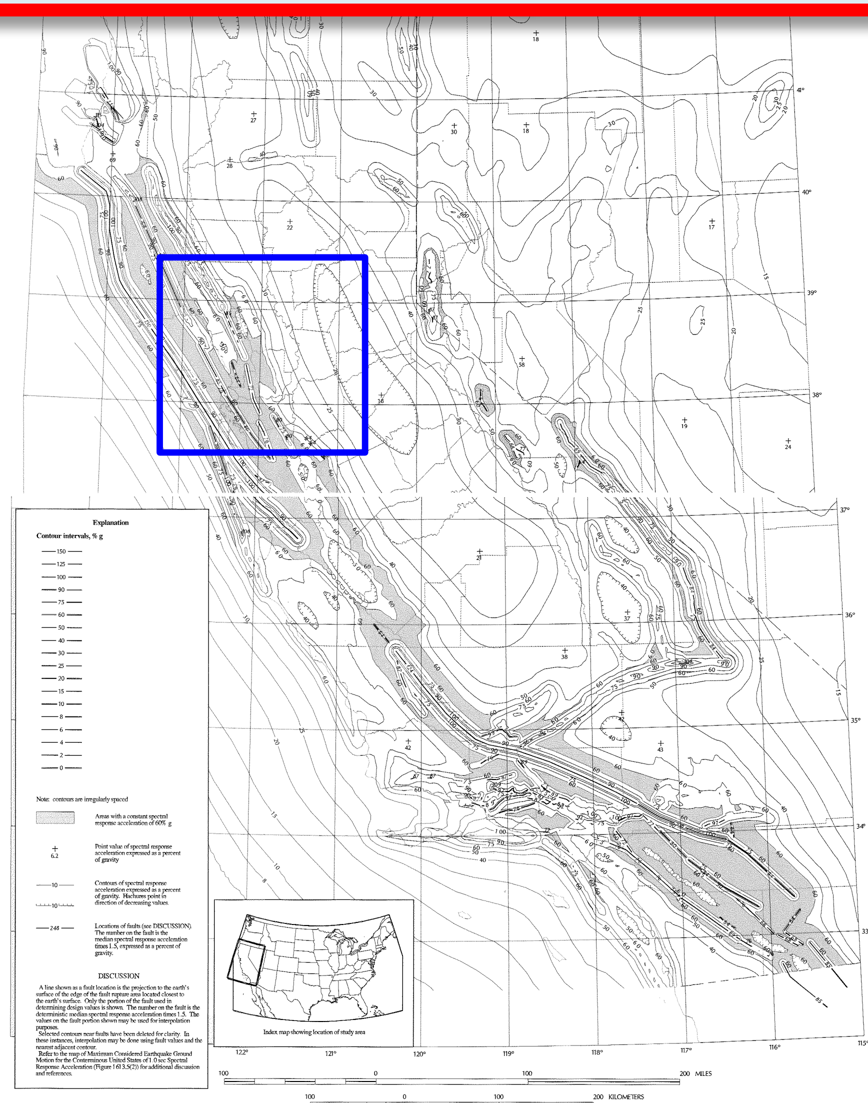
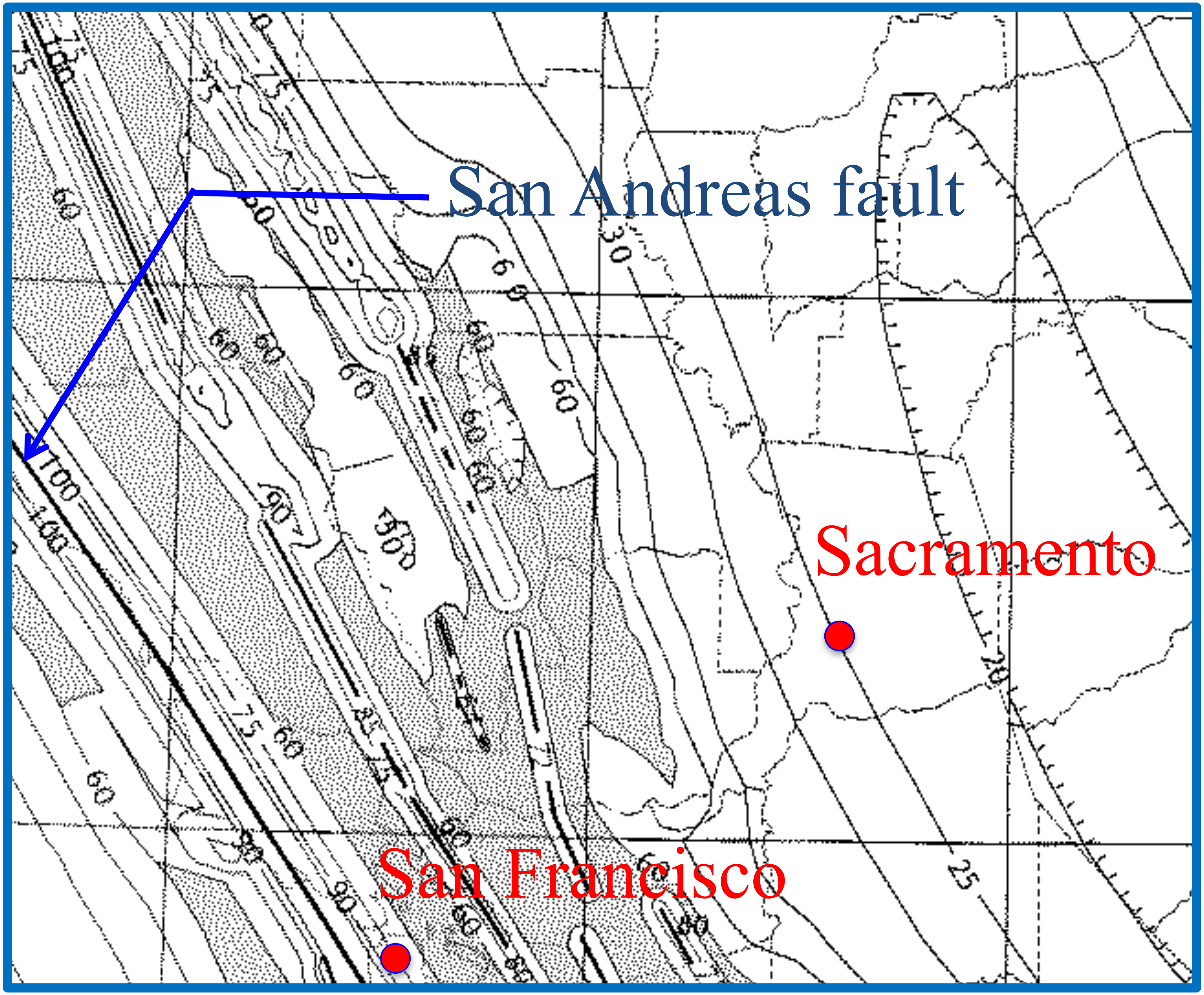
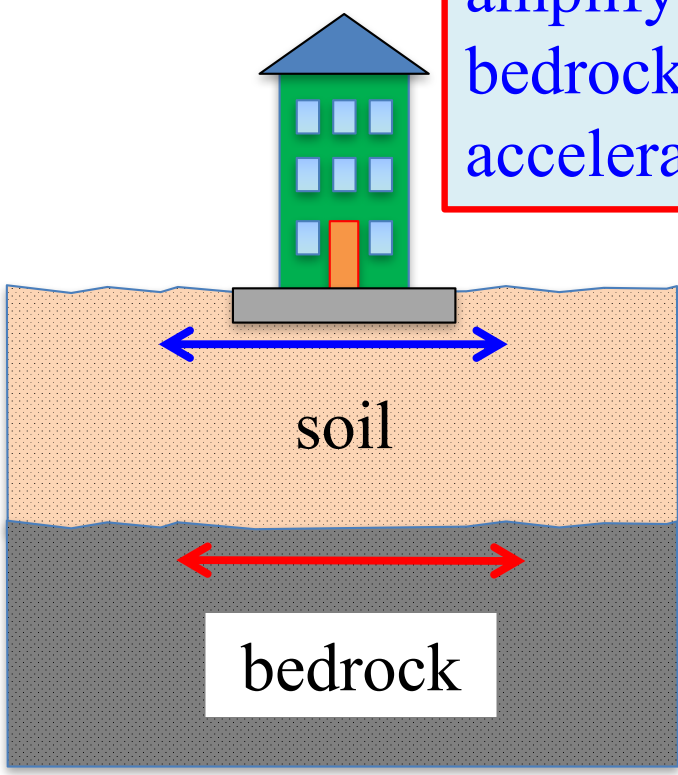


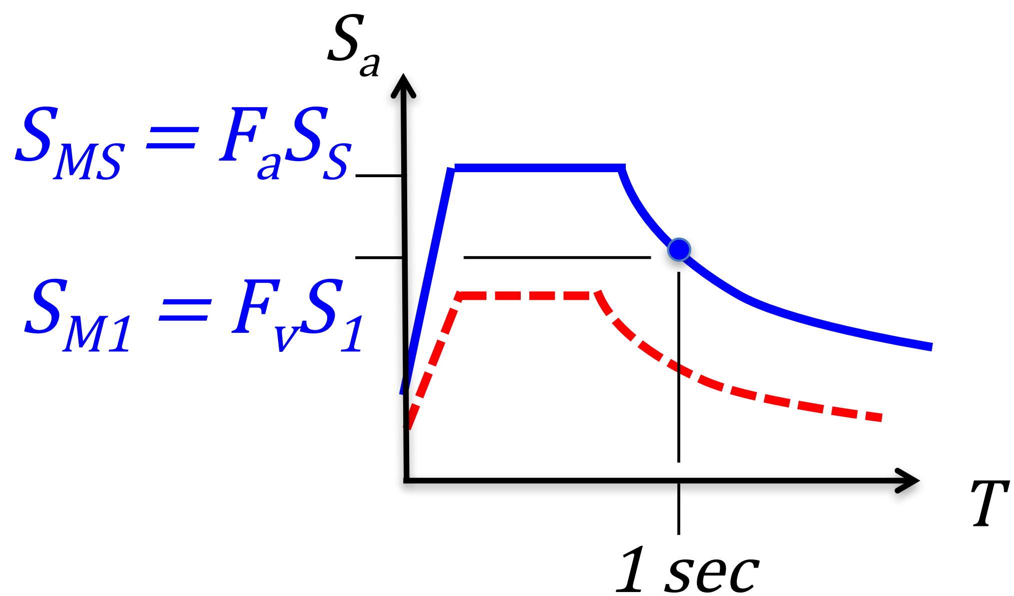
FIGURE 1613.5(4)—continued
MAXIMUM CONSIDERED EARTHQUAKE GROUND MOTION FOR REGION 1 OF
1.0 SEC SPECTRAL RESPONSE ACCELERATION (5% OF CRITICAL DAMPING), SITE CLASS B


San Andreas fault
Sacramento
San Francisco

Maximum credible acceleration at the foundation of the building depends on the seismicity and the soil at the site



Soft soil can amplify the bedrock acceleration



Site Class of Soil is found from IBC Table 1613.5.2 and then F_a and F_v from IBC Tables 1613.5.3 (1 and 2)

Site Class from Table 1613.5.2

TABLE 1613.5.2
SITE CLASS DEFINITIONS

SITE CLASS	SOIL PROFILE NAME	AVERAGE PROPERTIES IN TOP 100 feet, SEE SECTION 1613.5.5		
		Soil shear wave velocity, $\bar{v}_s$, (ft/s)	Standard penetration resistance, $\bar{N}$	Soil undrained shear strength, $\bar{s}_u$, (psf)
A	Hard rock	$\bar{v}_s > 5{,}000$	N/A	N/A
B	Rock	$2{,}500 < \bar{v}_s \leq 5{,}000$	N/A	N/A
C	Very dense soil and soft rock	$1{,}200 < \bar{v}_s \leq 2{,}500$	$\bar{N} > 50$	$\bar{s}_u \geq 2{,}000$
D	Stiff soil profile	$600 \leq \bar{v}_s \leq 1{,}200$	$15 \leq \bar{N} \leq 50$	$1{,}000 \leq \bar{s}_u \leq 2{,}000$
E	Soft soil profile	$\bar{v}_s < 600$	$\bar{N} < 15$	$\bar{s}_u < 1{,}000$
E	—	Any profile with more than 10 feet of soil having the following characteristics: 1. Plasticity index $PI > 20$, 2. Moisture content $w \geq 40\%$, and 3. Undrained shear strength $\bar{s}_u < 500$ psf		
F	—	Any profile containing soils having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. 2. Peats and/or highly organic clays ($H >$ 10 feet of peat and/or highly organic clay where H = thickness of soil) 3. Very high plasticity clays ($H >$25 feet with plasticity index $PI >$75) 4. Very thick soft/medium stiff clays ($H >$120 feet)		

For SI: 1 foot = 304.8 mm, 1 square foot = 0.0929 m^2, 1 pound per square foot = 0.0479 kPa. N/A = Not applicable

F_a and F_v from Tables 1613.5.3 (1 and 2)

TABLE 1613.5.3(1)
VALUES OF SITE COEFFICIENT F_a [a]

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT SHORT PERIOD				
	$S_s \le 0.25$	$S_s = 0.50$	$S_s = 0.75$	$S_s = 1.00$	$S_s \ge 1.25$
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
F	Note b	Note b	Note b	Note b	Note b

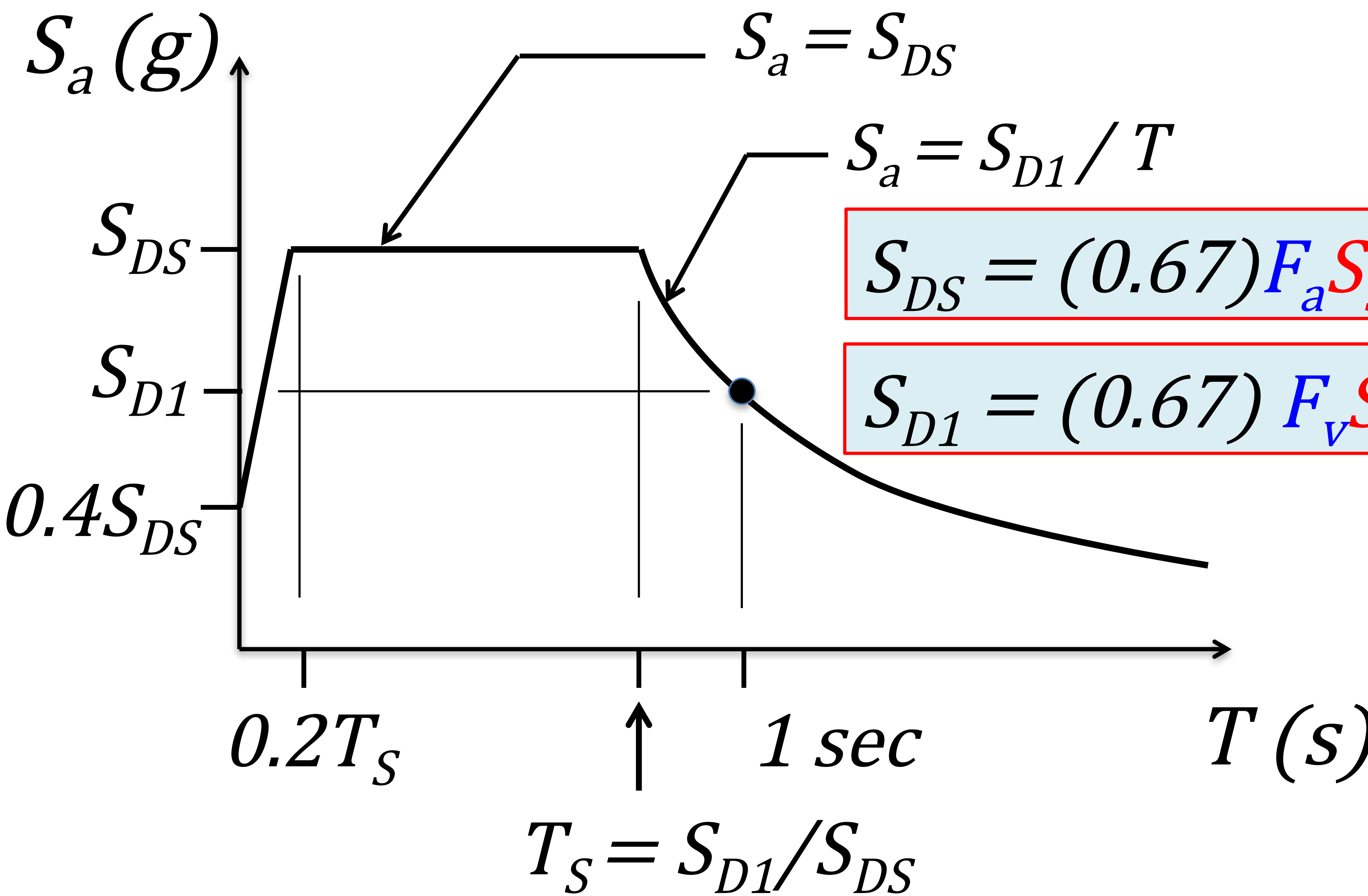
a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration at short period, S_s.
b. Values shall be determined in accordance with Section 11.4.7 of ASCE 7.

TABLE 1613.5.3(2)
VALUES OF SITE COEFFICIENT F_V [a]

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT 1-SECOND PERIOD				
	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
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	Note b	Note b	Note b	Note b	Note b

a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration at 1-second period, S_1.
b. Values shall be determined in accordance with Section 11.4.7 of ASCE 7.

IBC Design Response Spectrum



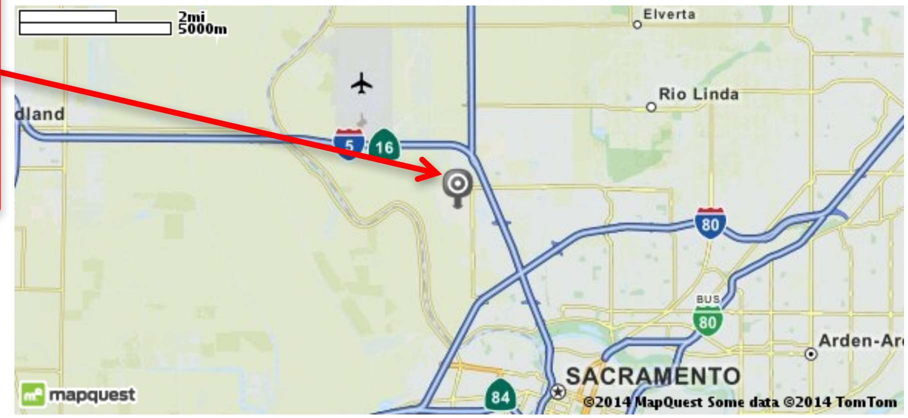
$$S_{DS} = (0.67) F_a S_S$$

$$S_{D1} = (0.67) F_v S_1$$

Can Find Accelerations and Spectra from USGS Website

38.6475°N, 121.54589°W

Site Class C – "Very Dense Soil and Soft Rock"
I/II/III

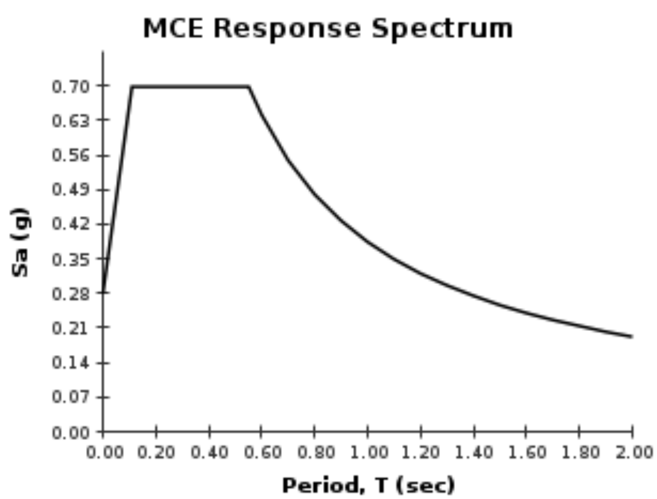


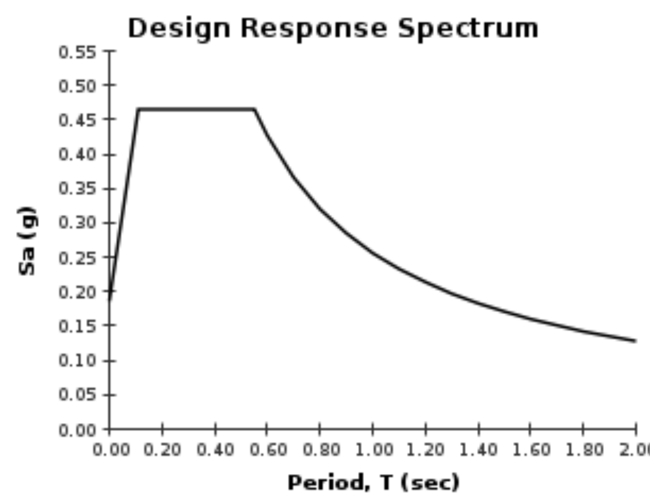
USGS–Provided Output

S_S = 0.602 g S_{MS} = 0.698 g S_{DS} = 0.465 g

S_1 = 0.248 g S_{M1} = 0.384 g S_{D1} = 0.256 g

Although this information is a product of the U.S. Geological Survey, we provide no warranty, expressed or implied, as to the accuracy of the data contained therein. This tool is not a substitute for technical subject-matter knowledge.





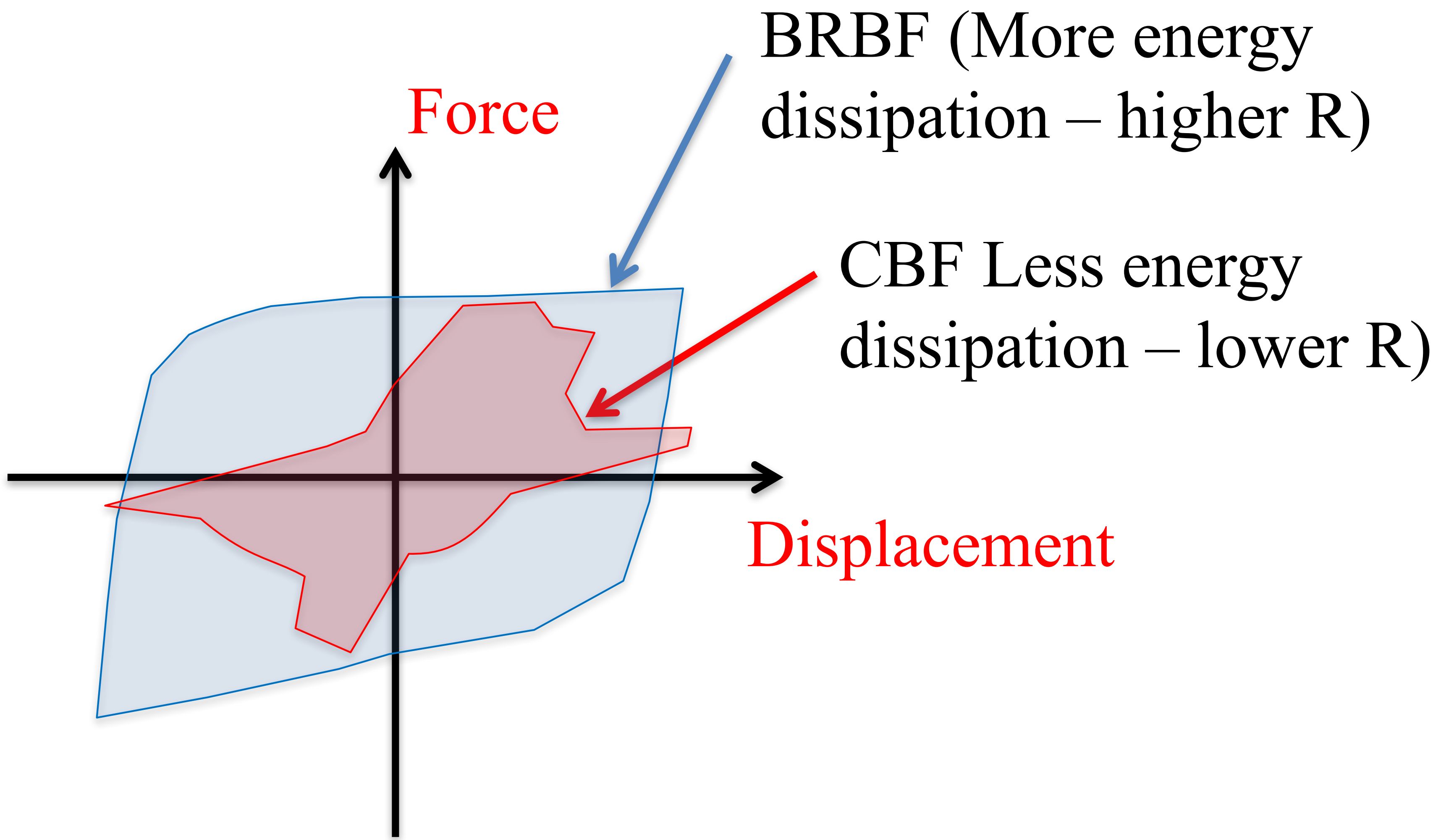
Energy Dissipating Capacity of the Lateral Force Resisting System

The base shear is adjusted for the earthquake energy dissipation of the Lateral Force Resisting System by dividing by a Response Modification Coefficient, R;

The Response Modification Coefficient is a measure of the energy dissipating characteristics of lateral force resisting system based on test results and performance in past earthquakes.

A high R value is assigned to systems that have performed well in past earthquakes and can effectively dissipate earthquake energy.

The Buckling Restrained Braced Frame (BRB) has more energy dissipating capacity than the Concentric Braced Frame (CBF) and so it has a larger R value

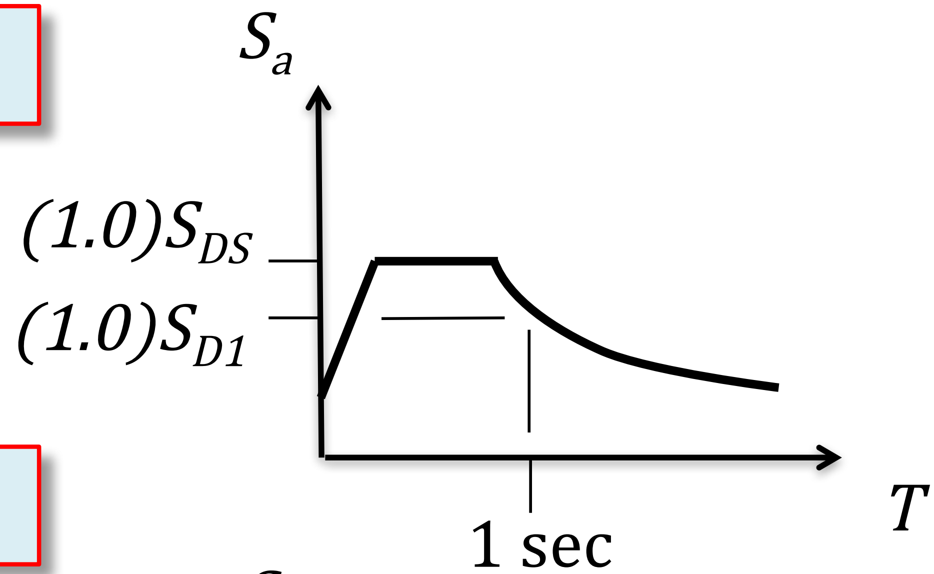


The Importance Factor is used to Design to an Expected Performance

Residential Building ($I_e = 1.0$)

$$I_e S_{DS} = (1.0)S_{DS} = S_{DS}$$

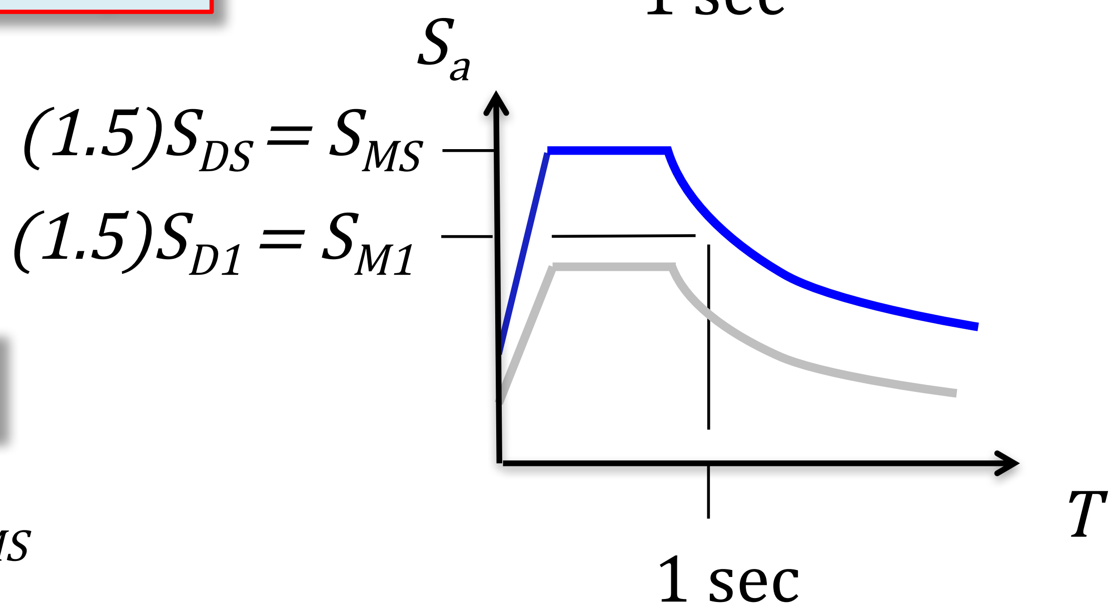
$$I_e S_{DS} = (1.0)S_{D1} = S_{D1}$$



Essential Facility ($I_e = 1.5$)

$$I_e S_{DS} = (1.5)S_{DS} = S_{MS}$$

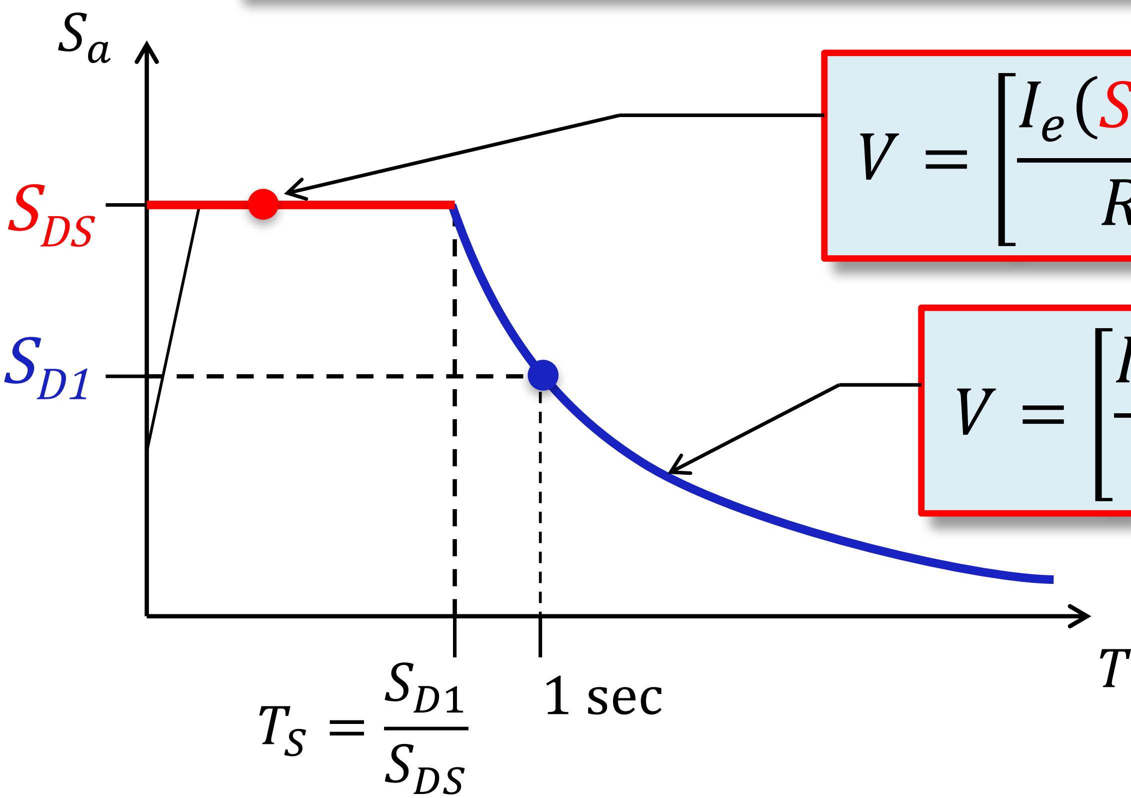
$$I_e S_{DS} = (1.5)S_{D1} = S_{M1}$$



Recall that $S_{DS} = (0.67)S_{MS}$

$$I_e S_{DS} = (1.5)(0.67)S_{MS} = S_{MS}$$

IBC Base Shear Expression



$$V = \left[\frac{I_e(S_{DS})}{R}\right] W \quad \text{for} \quad T \leq T_S$$

$$V = \left[\frac{I_e(S_{D1})}{TR}\right] W \quad \text{for} \quad T > T_S$$

Seismic Base Shear (V) depends on:

1. The seismic weight of the building (W);
2. The fundamental period of vibration of the building (T);
3. The earthquake acceleration at the base of the building (S_{DS} and S_{D1});
4. The energy dissipating capacity of the lateral force resisting system (R);
5. The desired performance level of the building (I_e).