

# Earthquake Loads and IBC Seismic Force Procedure II

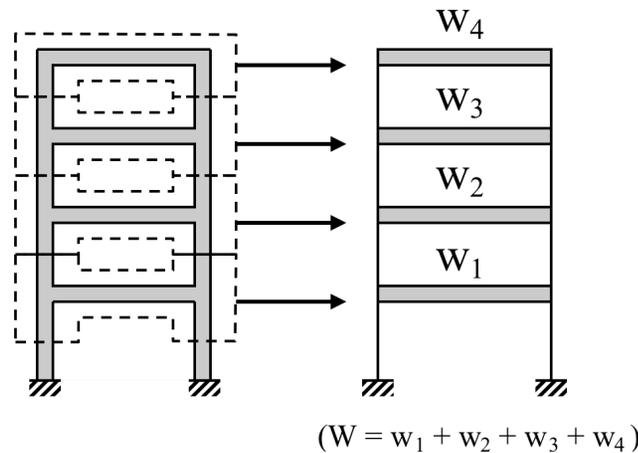
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# IBC Equivalent Static Seismic Force Procedure for Buildings

## Dynamic Model of a Building

Weights of walls are lumped at floor/roof levels



- The weight of each level,  $w_i$ , is the weight of the floor or roof level plus half the weight of the interior and exterior walls above the level and below the level (regions shown dotted above).
- The seismic weight,  $W$ , is the sum of the weight of all of the levels which is the total dead load of entire building

# IBC Estimate of the Fundamental Period of Vibration of a Building

Depends on building height and type of lateral force resisting system

$$T = C_t h_n^x \quad (\text{in seconds})$$

where:  $h_n$  = average roof height above base of building in feet

$x$  = exponent based on type of lateral force resisting system

= 0.8 for steel moment resisting frames

= 0.9 for concrete moment resisting frames

= 0.75 for eccentrically braced steel frames

= 0.75 for all other systems (shear walls, concentric frames, etc.)

$C_t$  = coefficient based on type of lateral force resisting system

= 0.028 for steel moment resisting frames

= 0.016 for concrete moment resisting frames

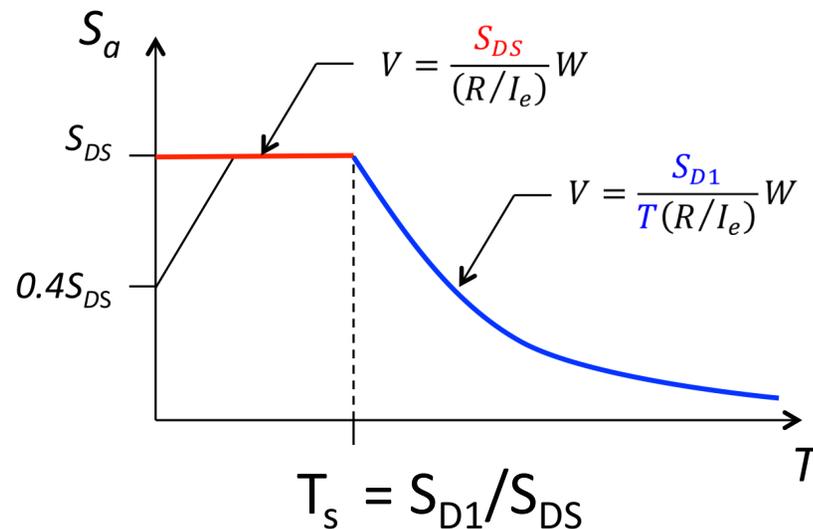
= 0.030 for eccentrically braced steel frames

= 0.020 for all other systems (shear walls, concentrically braced frames, etc.)

# IBC Base Shear

$$V = \begin{cases} \left[ \frac{I_e(S_{DS})}{R} \right] W & \text{for } T \leq T_s \\ \left[ \frac{I_e(S_{D1})}{T(R)} \right] W & \text{for } T > T_s \end{cases}$$

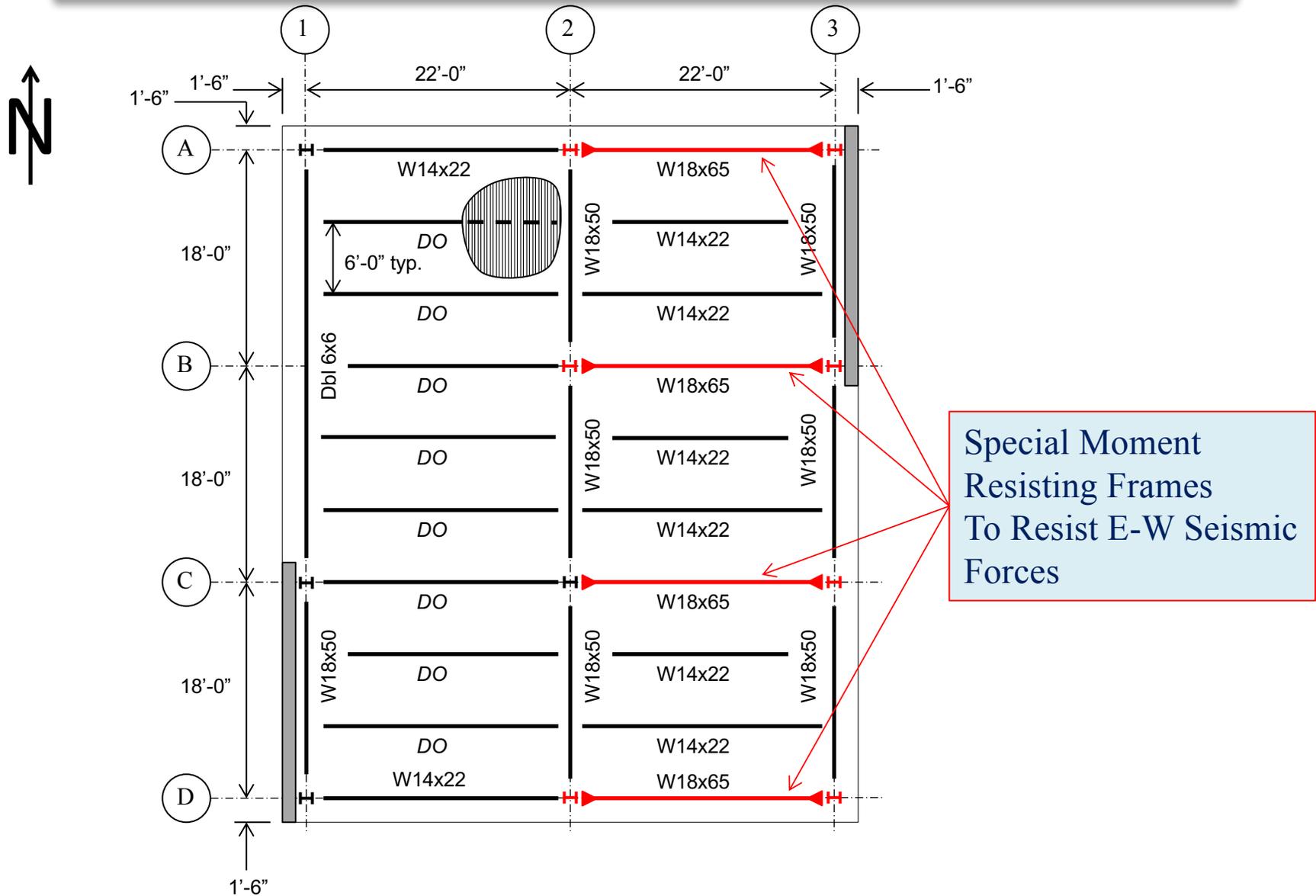
Note that the fundamental period of vibration of the building and the IBC Design Response Spectrum defines the design acceleration that governs the base shear



## Example Problem to Illustrate the Process of Finding the IBC Base Shear

Our CE 160 Lab Example Building is a retail building located in Sacramento, CA. The geotechnical engineer has determined that the soil at the site can be classified as Site Class C. Recall that the roof weight was determined in Lab #4 to be 29 psf. In addition, the non-structural exterior curtain walls weigh 15 psf (including the concrete walls) and it is estimated that the interior partition walls will add 14 k to the seismic weight. Determine the IBC base shear for earthquake acceleration in the East-West direction for our example building.

# Moment Resisting Frames Resist Seismic Force in the East-West Direction



# Find the Importance Factor

IBC Table 1604.5 and ASCE 7 Table 1.5-2

**TABLE 1604.5  
OCCUPANCY CATEGORY OF BUILDINGS AND OTHER STRUCTURES**

OCCUPANCY CATEGORY	NATURE OF OCCUPANCY
I	Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to: <ul style="list-style-type: none"> <li>• Agricultural facilities.</li> <li>• Certain temporary facilities.</li> <li>• Minor storage facilities.</li> </ul>
II	Buildings and other structures except those listed in Occupancy Categories I, III and IV
III	Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to: <ul style="list-style-type: none"> <li>• Covered structures whose primary occupancy is public assembly with an occupant load greater than 300.</li> <li>• Buildings and other structures with elementary school, secondary school or day care facilities with an occupant load greater than 250.</li> <li>• Buildings and other structures with an occupant load greater than 500 for colleges or adult education facilities.</li> <li>• Health care facilities with an occupant load of 50 or more resident patients, but not having surgery or emergency treatment facilities.</li> <li>• Jails and detention facilities.</li> <li>• Any other occupancy with an occupant load greater than 5,000.</li> <li>• Power-generating stations, water treatment for potable water, waste water treatment facilities and other public utility facilities not included in Occupancy Category IV.</li> <li>• Buildings and other structures not included in Occupancy Category IV containing sufficient quantities of toxic or explosive substances to be dangerous to the public if released.</li> </ul>
IV	Buildings and other structures designated as essential facilities, including but not limited to: <ul style="list-style-type: none"> <li>• Hospitals and other health care facilities having surgery or emergency treatment facilities.</li> <li>• Fire, rescue and police stations and emergency vehicle garages.</li> <li>• Designated earthquake, hurricane or other emergency shelters.</li> <li>• Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response.</li> <li>• Power-generating stations and other public utility facilities required as emergency backup facilities for Occupancy Category IV structures.</li> <li>• Structures containing highly toxic materials as defined by Section 307 where the quantity of the material exceeds the maximum allowable quantities of Table 307.1.(2).</li> <li>• Aviation control towers, air traffic control centers and emergency aircraft hangars.</li> <li>• Buildings and other structures having critical national defense functions</li> <li>• Water treatment facilities required to maintain water pressure for fire suppression.</li> </ul>

**Table 1.5-2 Importance Factors by Risk Category of Buildings and Other Structures for Snow, Ice, and Earthquake Loads<sup>a</sup>**

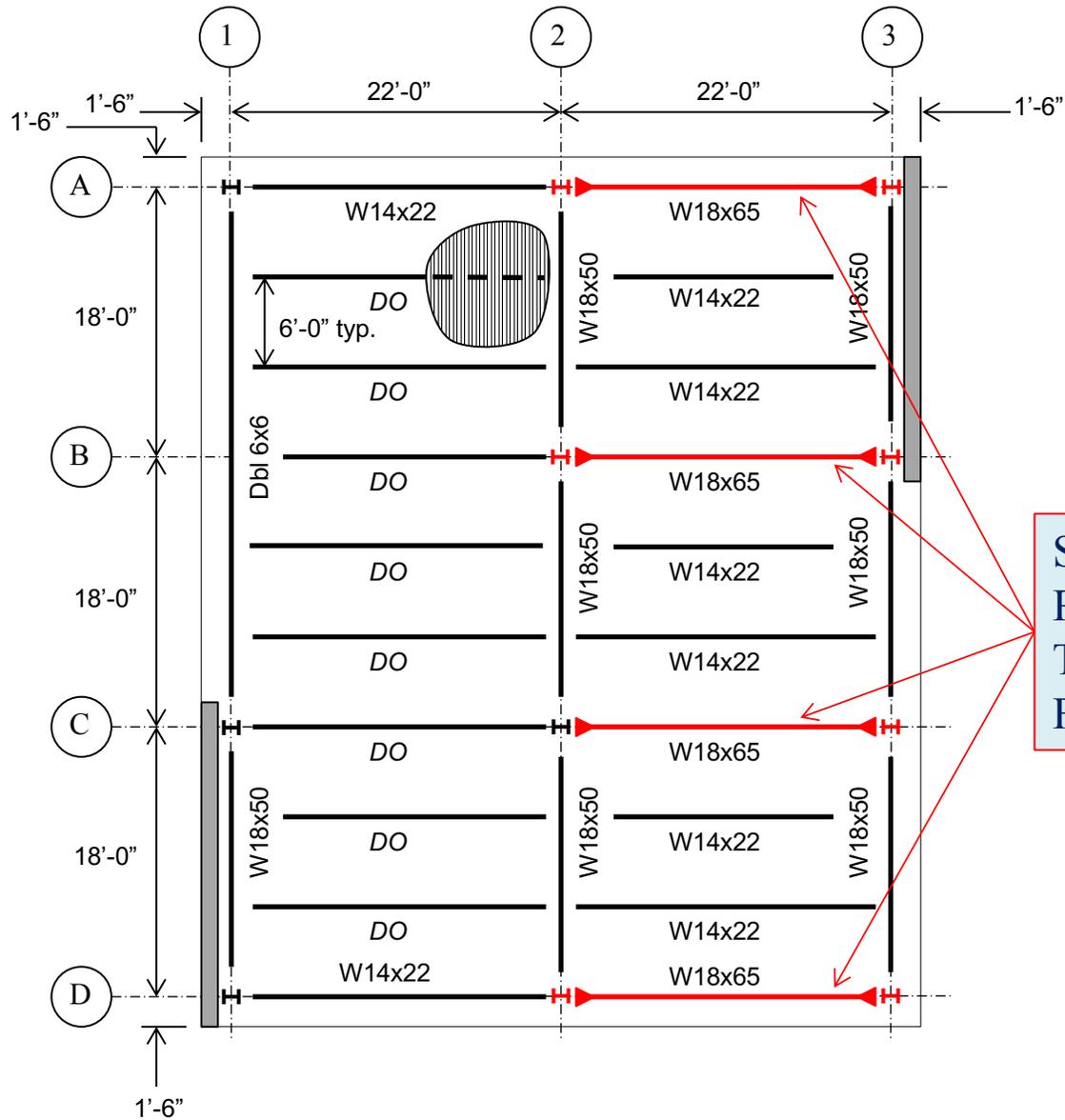
Risk Category from Table 1.5-1	Snow Importance Factor, $I_s$	Ice Importance Factor—Thickness, $I_i$	Ice Importance Factor—Wind, $I_w$	Seismic Importance Factor, $I_e$
I	0.80	0.80	1.00	1.00
II	1.00	1.00	1.00	1.00
III	1.10	1.25	1.00	1.25
IV	1.20	1.25	1.00	1.50

<sup>a</sup>The component importance factor,  $I_p$ , applicable to earthquake loads, is not included in this table because it is dependent on the importance of the individual component rather than that of the building as a whole, or its occupancy. Refer to Section 13.1.3.

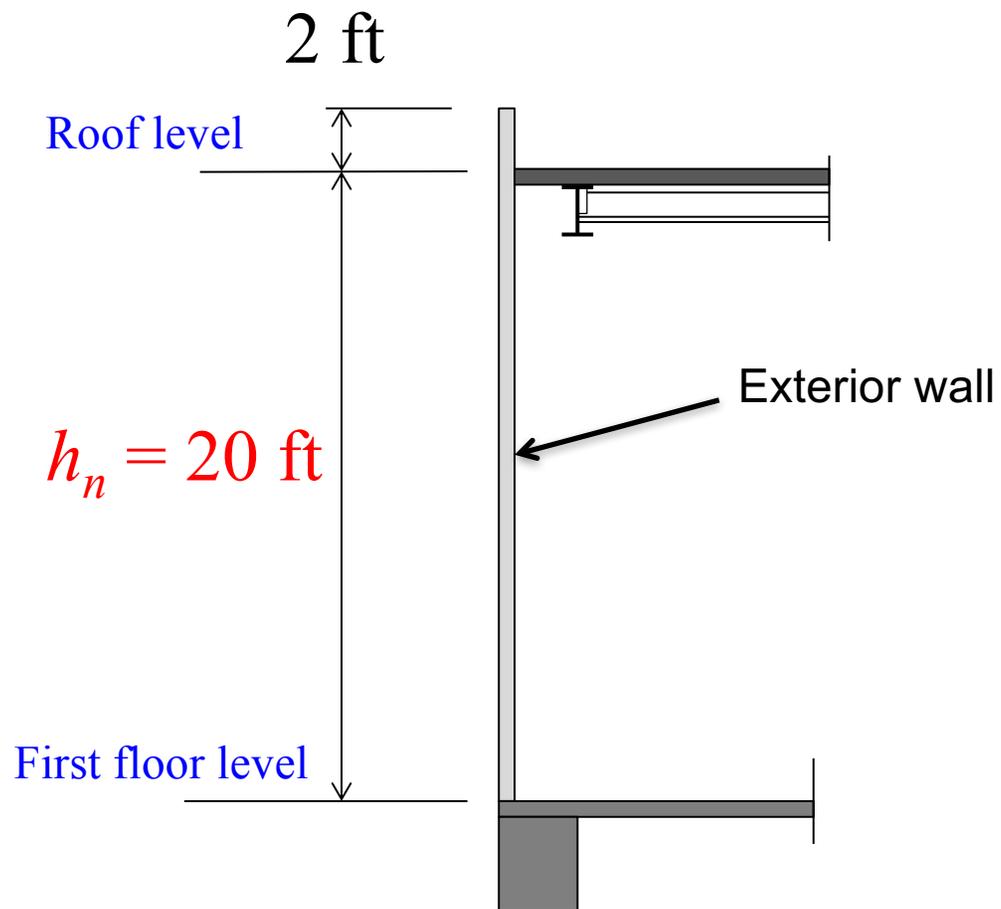
**Our example retail building is a Category II building so:**

$$I_e = 1.0$$

# Estimate the Fundamental Period of the Building



# Estimate the Fundamental Period of the Building



## Find the IBC Estimate of the Fundamental Period of Vibration of the Building

$$T = C_t h_n^x \quad (\text{in seconds})$$

- where:  $h_n$  = average roof height above base of building in feet  
 $x$  = exponent based on type of lateral force resisting system  
= 0.8 for steel moment resisting frames  
= 0.9 for concrete moment resisting frames  
= 0.75 for eccentrically braced steel frames  
= 0.75 for all other systems (shear walls, concentric frames, etc.)  
 $C_t$  = coefficient based on type of lateral force resisting system  
= 0.028 for steel moment resisting frames  
= 0.016 for concrete moment resisting frames  
= 0.030 for eccentrically braced steel frames  
= 0.020 for all other systems (shear walls, concentrically braced frames, etc.)

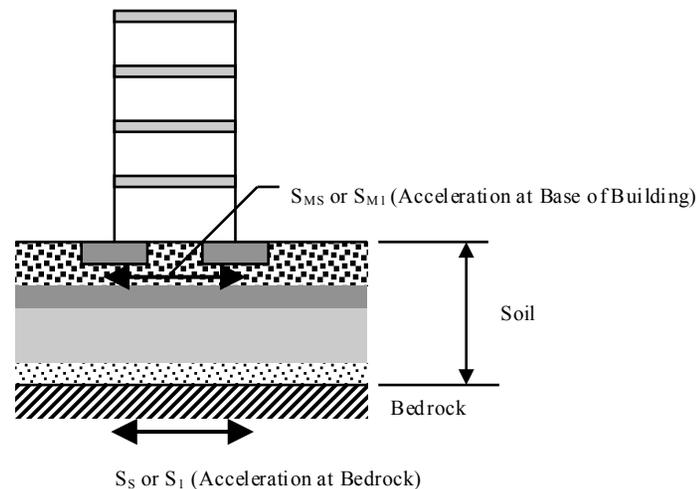
**For our example building in the East-West Direction the Lateral Force Resisting System are Moment Resisting Frames on lines A, B, C, and D and the roof height is 20 feet.**

$$T = C_t h_n^x = (0.028)(20)^{(0.8)} = 0.308 \text{ seconds}$$

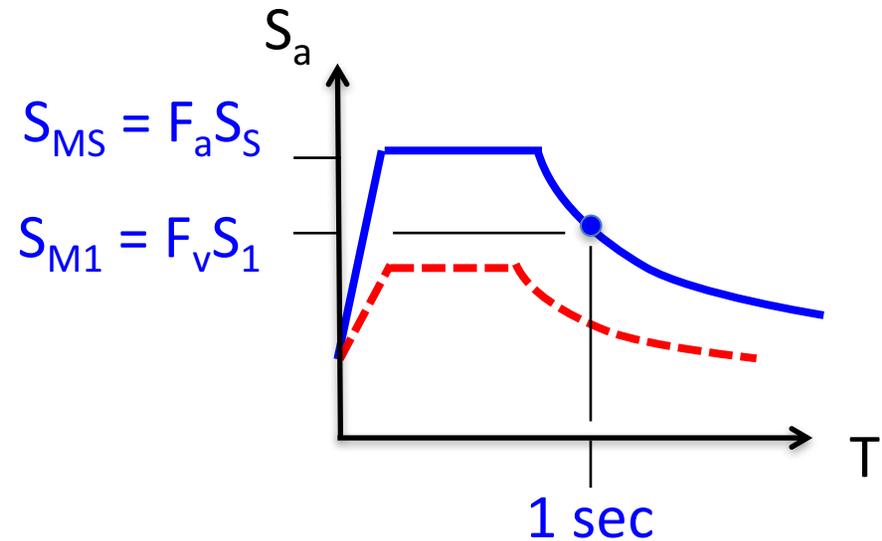
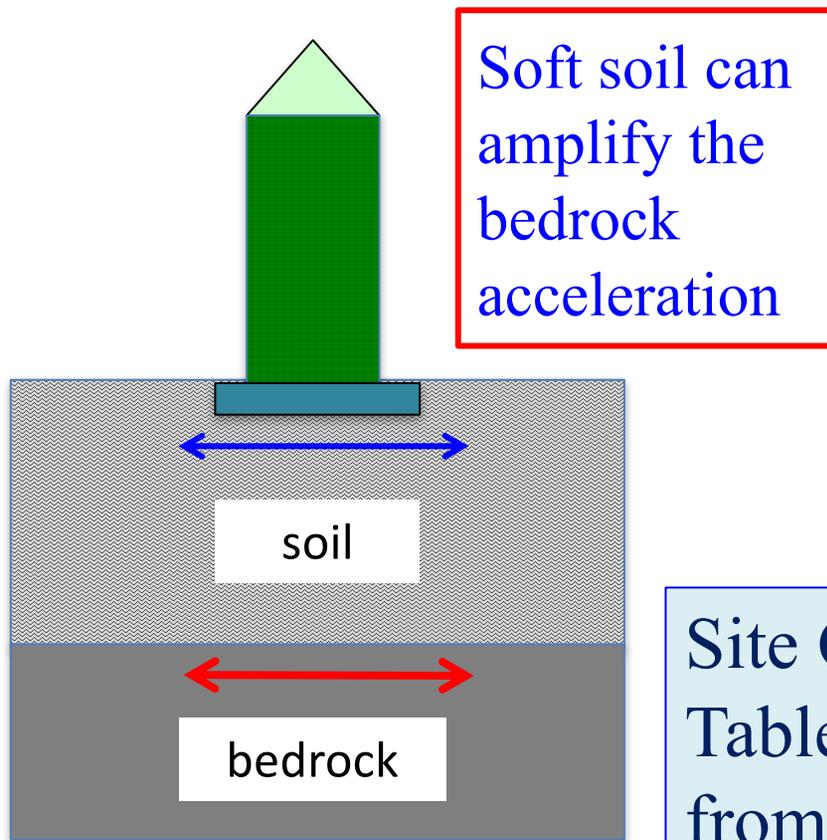
# Earthquake Acceleration at the Base of the Building

The acceleration at the base of the building depends on:

- The seismicity of the building site ( $S_S$  and  $S_1$ : maximum credible ground accelerations due to earthquake at bedrock level)
- The soil at the site ( $S_{MS}$  and  $S_{M1}$ : soft soil can amplify earthquake acceleration at bedrock)



# Find the Maximum Credible Acceleration at the Foundation of the Building

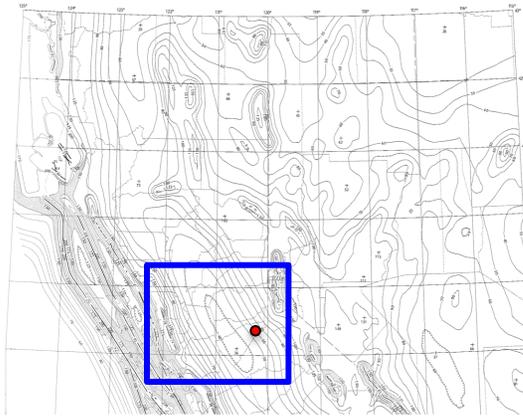


Site Class of Soil is found from IBC Table 1613.5.2 and then  $F_a$  and  $F_v$  from IBC Tables 1613.5.3 (1 and 2)

# Find Design Accelerations $S_{DS}$ and $S_{D1}$

## 1. Find the Maximum Short and One-Second Period Ground Accelerations at Bedrock

$S_S$  = Maximum Short Period (0.2 sec) Acceleration at bedrock: Fig. 1613.5(3)



**For Sacramento use  $S_S = 0.6$**

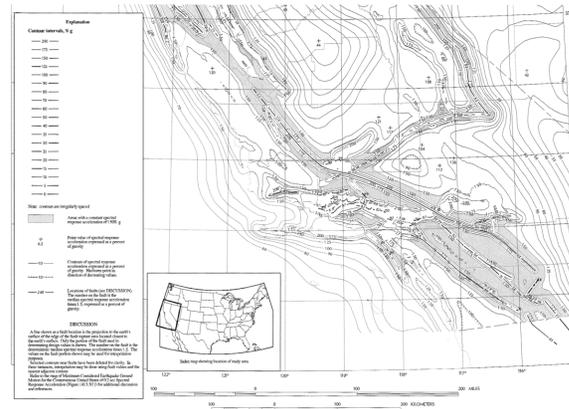
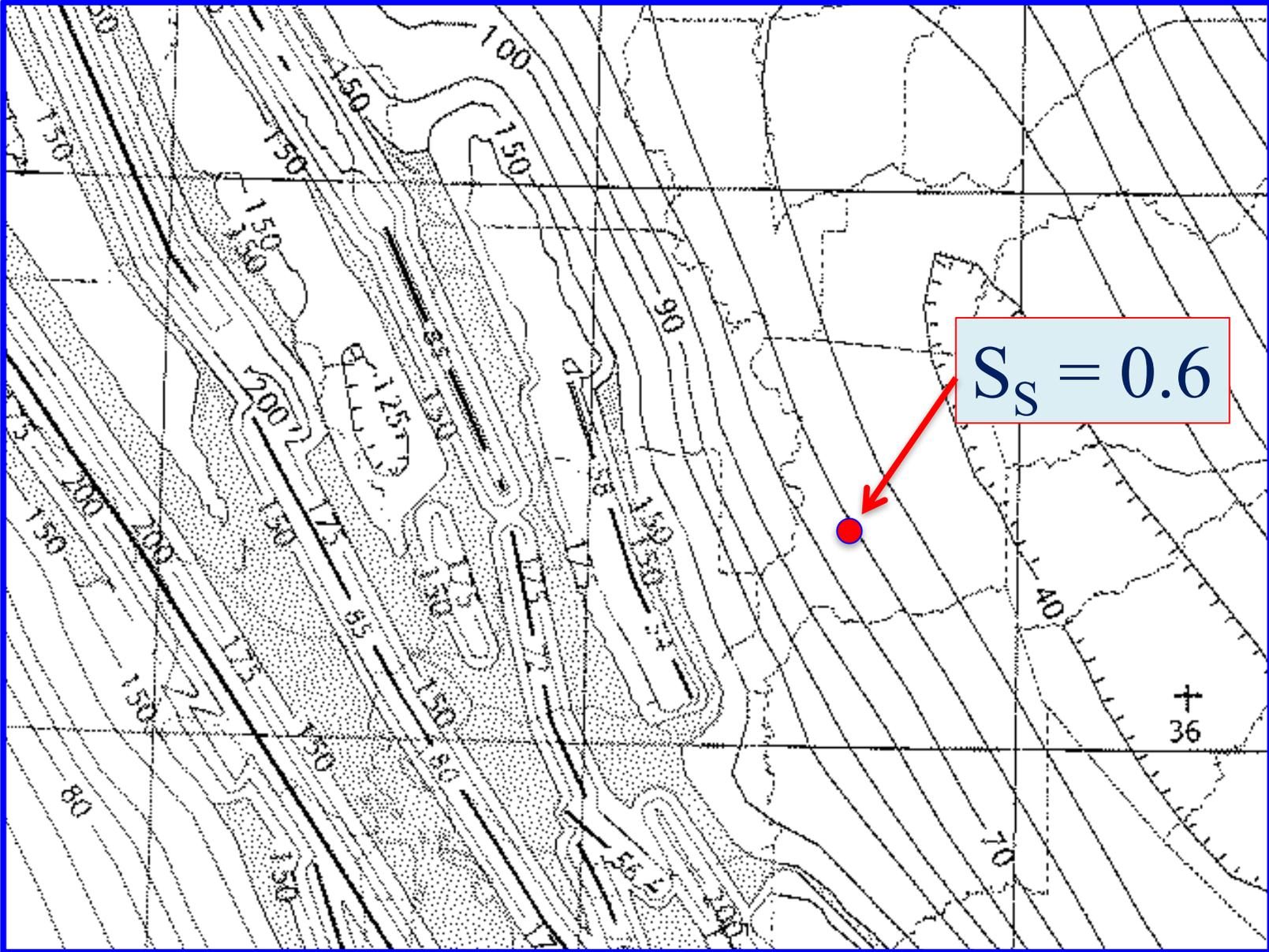
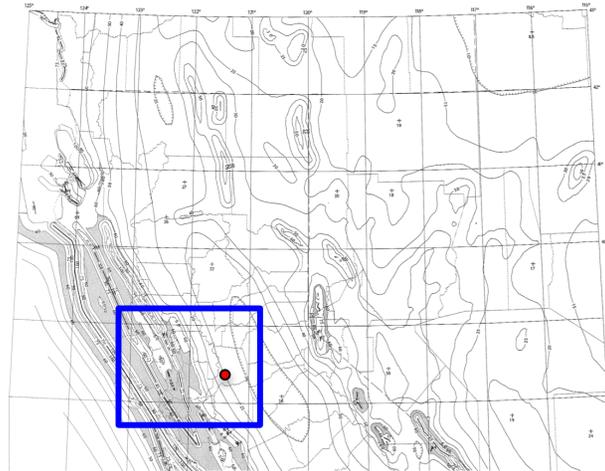


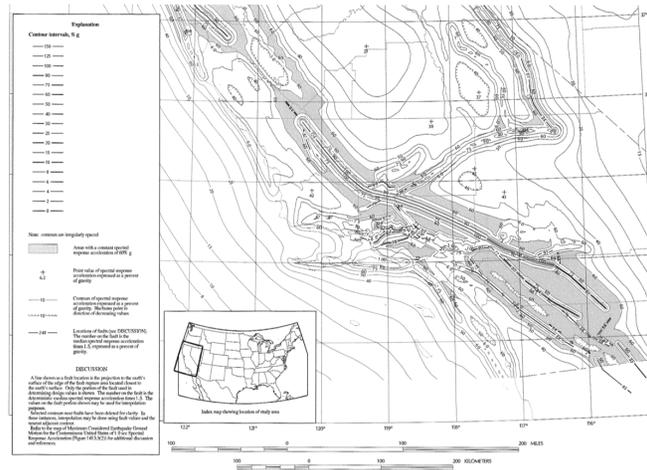
FIGURE 1613.5(3)—continued  
MAXIMUM CONSIDERED EARTHQUAKE GROUND MOTION FOR REGION 1 OF  
0.2 SEC SPECTRAL RESPONSE ACCELERATION (5% OF CRITICAL DAMPING), SITE CLASS B

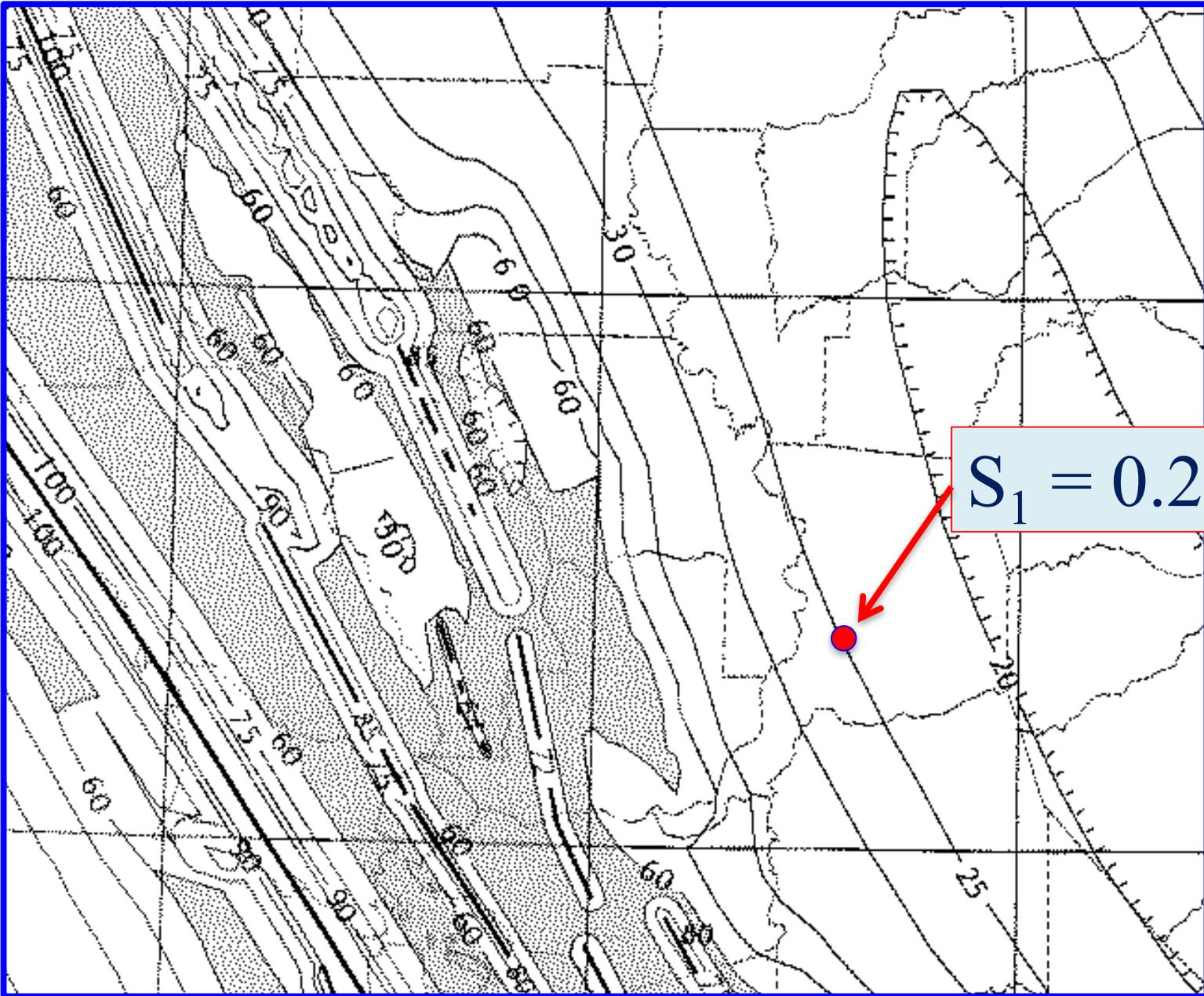


$S_1$  = Maximum One-Second Period Acceleration at bedrock: Fig. 1613.5(4)



**For Sacramento use  $S_1 = 0.25$**





$S_1 = 0.25$

# Find Soil Amplification Factors $F_a$ and $F_v$ from Tables 1613.5.3 (1 and 2)

$F_a$  = Soil Amplification Factor: Table 1613.5.3(1)

$F_v$  = Soil Amplification Factor: Table 1613.5.3(2)

Note that Soil Amplification Factors depend on the IBC Site Class (Table 1613.5.2) and  $S_S$  and  $S_I$ .  
Linear interpolation of Tables 1613.5.3 is OK.

**For our Example -- Site Class C (from the geotechnical investigation of the site)**

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<sup>2</sup>, 1 pound per square foot = 0.0479 kPa. N/A = Not applicable

Find  $F_a$

$$S_S = 0.6$$

TABLE 1613.5.3(1)  
VALUES OF SITE COEFFICIENT  $F_a$  <sup>a</sup>

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT SHORT PERIOD				
	$S_S \leq 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \geq 1.25$
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.

Site Class C and  $S_S = 0.6$  so linearly interpolate between 1.2 ( $S_S = 0.5$ ) and 1.1 ( $S_S = 0.75$ ) from Table 1613.3.3(1)

$$\frac{0.75 - 0.6}{0.75 - 0.5} = \frac{1.1 - F_a}{1.1 - 1.2}$$

$$F_a = 1.16$$

Find  $F_v$

$$S_1 = 0.25$$

TABLE 1613.5.3(2)  
VALUES OF SITE COEFFICIENT  $F_v^a$

SITE CLASS	MAPPED SPECTRAL RESPONSE ACCELERATION AT 1-SECOND PERIOD				
	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
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

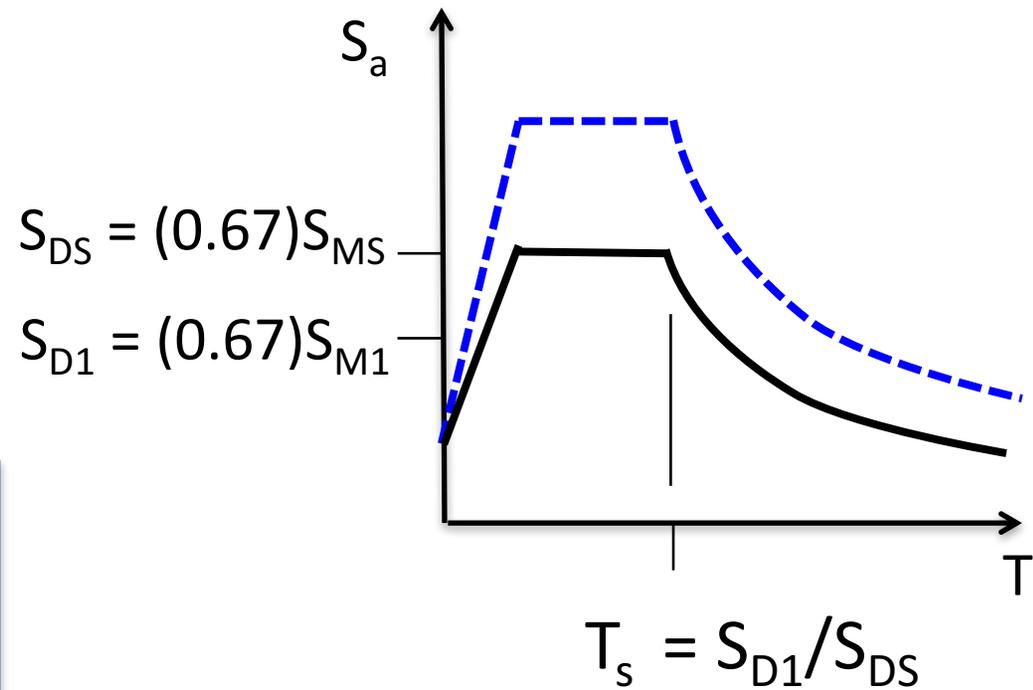
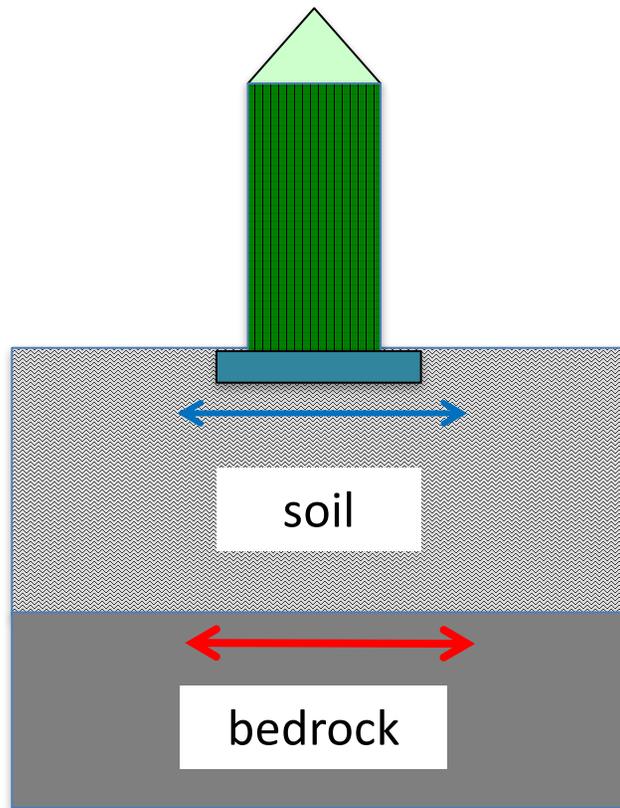
- a. Use straight-line interpolation for intermediate values of mapped spectral response acceleration at 1-second period,  $S_1$ .  
b. Values shall be determined in accordance with Section 11.4.7 of ASCE 7.

Site Class C and  $S_1 = 0.25$  so linearly interpolate between 1.6 ( $S_1 = 0.2$ ) and 1.5 ( $S_1 = 0.3$ ) from Table 1613.3.3(2)

$$\frac{0.30 - 0.25}{0.30 - 0.20} = \frac{1.5 - F_v}{1.5 - 1.6}$$

$$F_v = 1.55$$

Design Level Earthquake Accelerations are 2/3 of the Maximum Credible Earthquake Acceleration



# Calculate Design Accelerations $S_{DS}$ and $S_{D1}$

$$S_{MS} = F_a S_S = (1.16)(0.6) = 0.696 g$$

$$S_{M1} = F_v S_1 = (1.55)(0.25) = 0.3875 g$$

$$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3} F_a S_S = \frac{2}{3} (1.16)(0.6) = 0.464 g$$

$$S_{D1} = \frac{2}{3} S_{M1} = \frac{2}{3} F_v S_1 = \frac{2}{3} (1.55)(0.25) = 0.258 g$$

Checks with USGS website (Now the website calculates  $S_{MS}$ ,  $S_{DS}$ ,  $S_{M1}$ , and  $S_{D1}$ )

We can now calculate  $T_s$ :

$$T_s = \frac{S_{D1}}{S_{DS}} = \frac{0.258}{0.464} = 0.557 \text{ seconds}$$

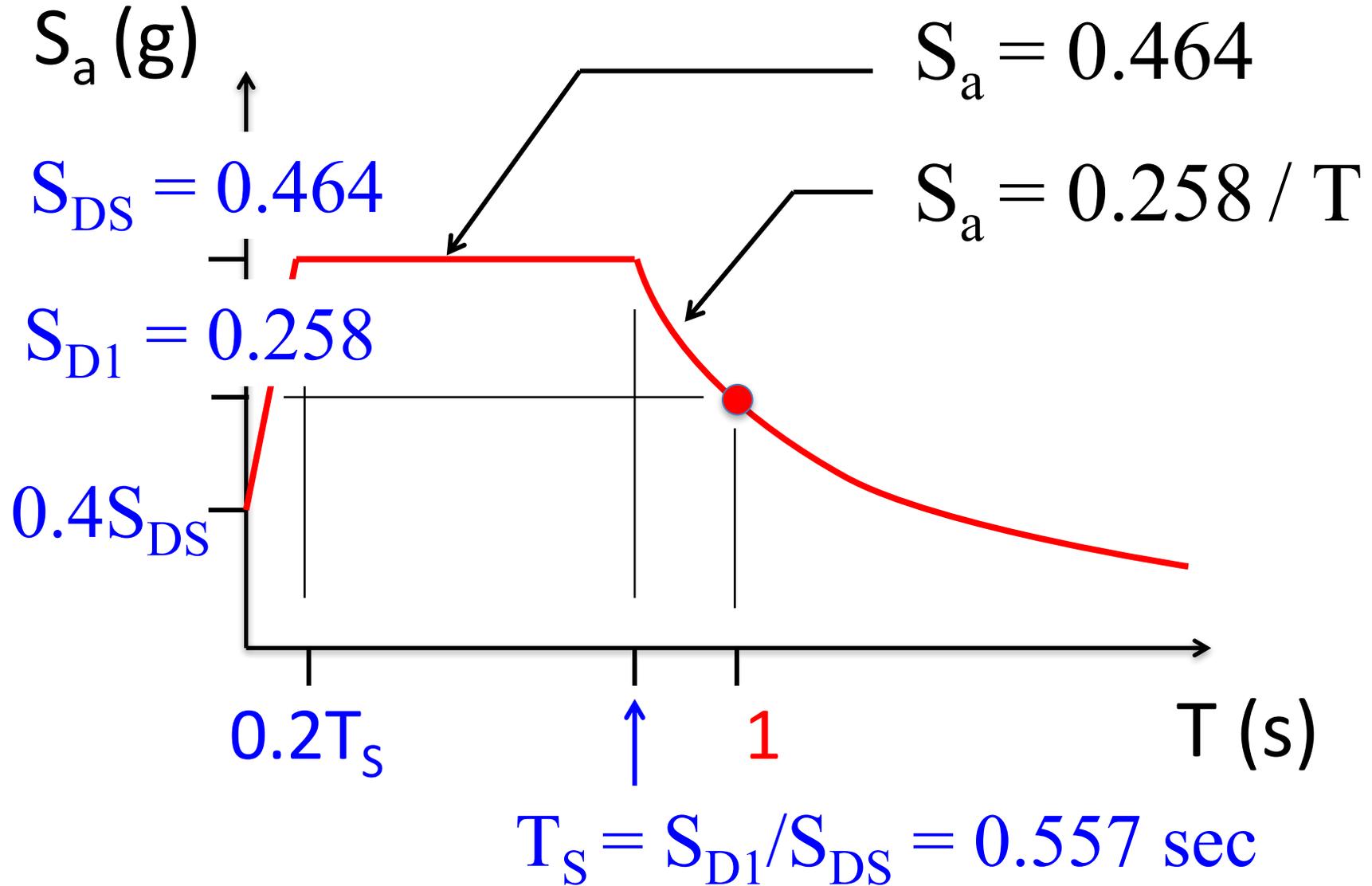
Note that:

$$T = 0.308 < T_s = 0.557$$

so:

$$V = \frac{S_{DS}}{(R/I_e)} W$$

# IBC Design Response Spectrum



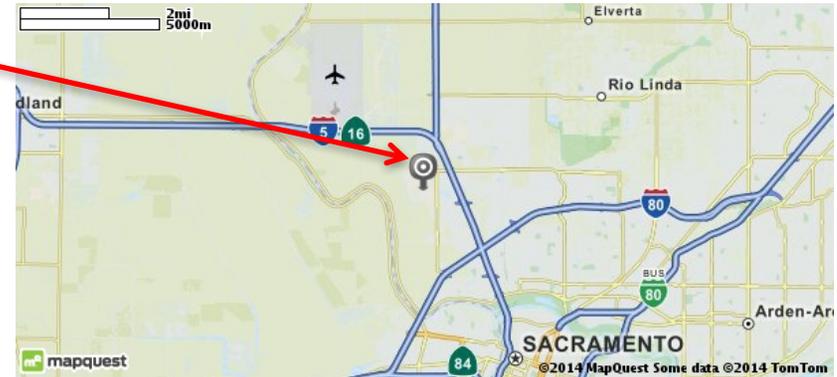
# Can Verify Accelerations and Spectra from USGS Website

38.6475°N, 121.54589°W

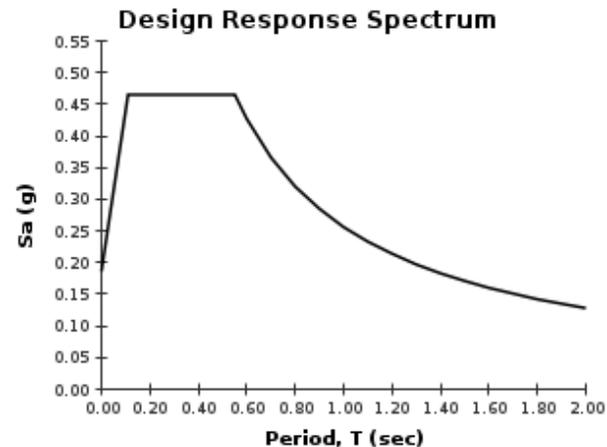
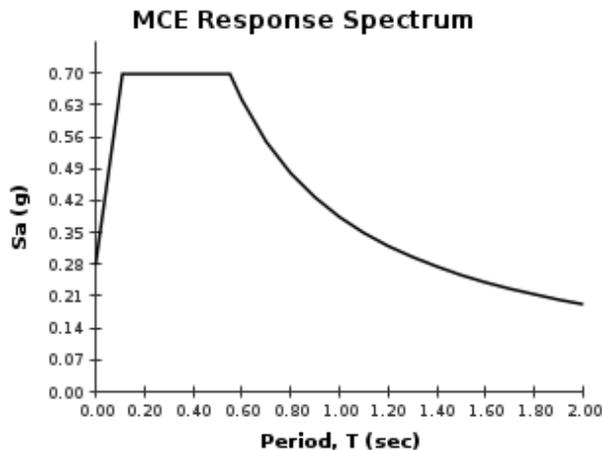
Site Class C – “Very Dense Soil and Soft Rock”  
I/II/III

USGS–Provided Output

$S_S = 0.602 \text{ g}$     $S_{MS} = 0.698 \text{ g}$     $S_{DS} = 0.465 \text{ g}$   
 $S_1 = 0.248 \text{ g}$     $S_{M1} = 0.384 \text{ g}$     $S_{D1} = 0.256 \text{ g}$



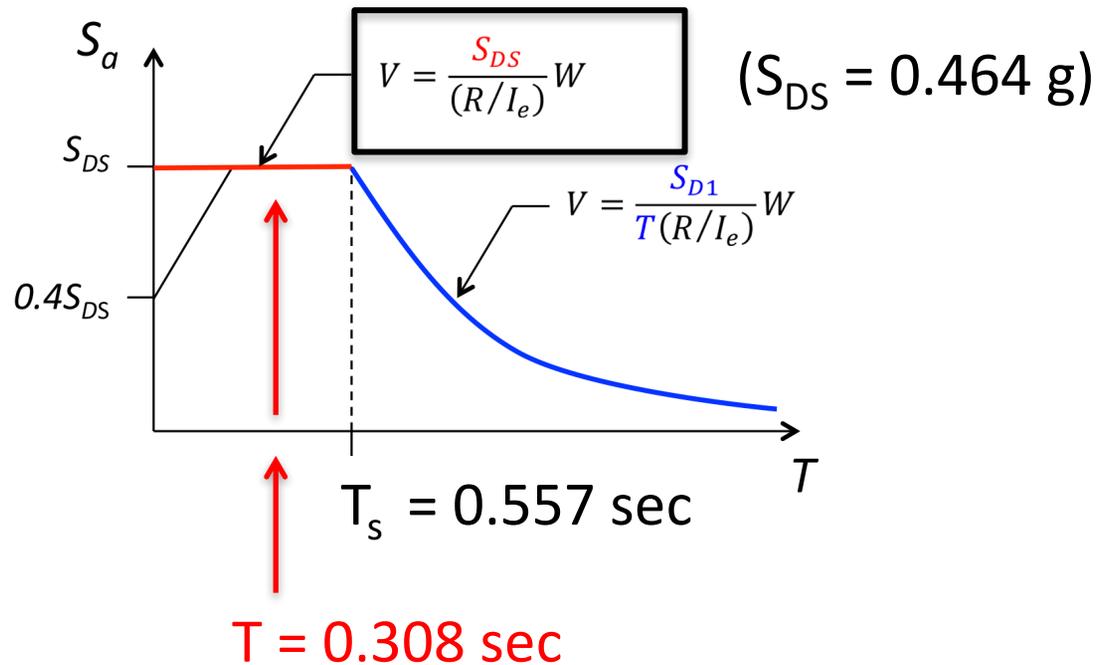
Although this information is a product of the U.S. Geological Survey, we provide no warranty, expressed or implied, as to the accuracy of the data contained therein. This tool is not a substitute for technical subject-matter knowledge.



# IBC Base Shear

$$V = \begin{cases} \left[ \frac{I_e(S_{DS})}{R} \right] W & \text{for } T \leq T_s \\ \left[ \frac{I_e(S_{D1})}{T(R)} \right] W & \text{for } T > T_s \end{cases}$$

Note that the fundamental period of vibration of the building and the IBC Design Response Spectrum defines the design acceleration that governs the base shear



# Find the Response Modification Coefficient

Table 12.2-1 (Continued)

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	Response Modification Coefficient, $R^a$	Overstrength Factor, $\Omega_o^b$	Deflection Amplification Factor, $C_d^b$	Structural System Limitations Including Structural Height, $h_u$ (ft) Limits <sup>c</sup>				
					Seismic Design Category				
					B	C	D <sup>e</sup>	E <sup>e</sup>	F <sup>e</sup>
<b>C. MOMENT-RESISTING FRAME SYSTEMS</b>									
1. Steel special moment frames	14.1 and 12.2.5.5	8	3	5½	NL	NL	NL	NL	NL
2. Steel special truss moment frames	14.1	7	3	5½	NL	NL	160	100	NP
3. Steel intermediate moment frames	12.2.5.7 and 14.1	4½	3	4	NL	NL	35 <sup>h</sup>	NP <sup>h</sup>	NP <sup>h</sup>
4. Steel ordinary moment frames	12.2.5.6 and 14.1	3½	3	3	NL	NL	NP <sup>h</sup>	NP <sup>h</sup>	NP <sup>h</sup>
5. Special reinforced concrete moment frames <sup>a</sup>	12.2.5.5 and 14.2	8	3	5½	NL	NL	NL	NL	NL
6. Intermediate reinforced concrete moment frames	14.2	5	3	4½	NL	NL	NP	NP	NP
7. Ordinary reinforced concrete moment frames	14.2	3	3	2½	NL	NP	NP	NP	NP
8. Steel and concrete composite special moment frames	12.2.5.5 and 14.3	8	3	5½	NL	NL	NL	NL	NL
9. Steel and concrete composite intermediate moment frames	14.3	5	3	4½	NL	NL	NP	NP	NP
10. Steel and concrete composite partially restrained moment frames	14.3	6	3	5½	160	160	100	NP	NP
11. Steel and concrete composite ordinary moment frames	14.3	3	3	2½	NL	NP	NP	NP	NP
12. Cold-formed steel—special bolted moment frame <sup>a</sup>	14.1	3½	3 <sup>g</sup>	3½	35	35	35	35	35
<b>D. DUAL SYSTEMS WITH SPECIAL MOMENT FRAMES CAPABLE OF RESISTING AT LEAST 25% OF PRESCRIBED SEISMIC FORCES</b>									
1. Steel eccentrically braced frames	14.1	8	2½	4	NL	NL	NL	NL	NL
2. Steel special concentrically braced frames	14.1	7	2½	5½	NL	NL	NL	NL	NL
3. Special reinforced concrete shear walls <sup>d</sup>	14.2	7	2½	5½	NL	NL	NL	NL	NL
4. Ordinary reinforced concrete shear walls <sup>d</sup>	14.2	6	2½	5	NL	NL	NP	NP	NP
5. Steel and concrete composite eccentrically braced frames	14.3	8	2½	4	NL	NL	NL	NL	NL
6. Steel and concrete composite special concentrically braced frames	14.3	6	2½	5	NL	NL	NL	NL	NL

Continued

**For our building in the East-West Direction the Lateral Force Resisting System is a Special Moment Resisting Frame**

**From ASCE 7 Table 12.2-1:**

$$R = 8$$

## Calculate the East–West Base Shear

$$V = \frac{S_{DS}}{(R/I_e)} W = \frac{0.464}{(8/1.0)} W = (0.058)W$$